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Calvin G. Clyde

Duard S. Woffinden

Graeme Duncan

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WATER WELL PUMP EFFICIENCY MONITOR UNITS

by

Calvin G. Clyde,
Duard S. Woffinden,
and
Graeme Duncan

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Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

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During the course of the project Duard S. Woffinden, one of the authors, passed away. His contributions to the success of this and many other projects at UWRL will long be remembered. This volume is dedicated to his memory.

Calvin G. Clyde

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CHAPTER I

INTRODUCTION

The Problem and Opportunity

As the costs for pumping municipal, industrial and irrigation water rise, owners and the public are giving increased attention to energy conservation. One way to conserve energy is to operate water pumps at or near peak efficiency. The measurement of pump efficiency usually requires special test equipment, a skilled operator and time to perform the test. Owners may find it more economical to waste power than to monitor for inefficiencies. One way to help change this situation is to develop inexpensive equipment for unskilled people to use to obtain rapid measurements of pump efficiency under typical operating conditions. Such equipment would enable pump owners to find out quickly when their equipment was operating below maximum efficiency so the problems could be corrected. Prudent and timely maintenance work would pay off by making the pumping operation more ecoomical and conserving energy resources.

Objectives and Scope

The general objectives of this project were to develop, fabricate, install, field test and evaluate low and medium cost pump efficiency monitor units for use by owners, operators or consultants. The low cost unit utilizes a "pitot" type flow rate meter while the medium cost unit includes an ultrasonic doppler type strap-on flow meter. Both units require simple computations to be done by the non-skilled operator using a hand held calculator. Recommendations for winter operation of the units were to be considered.

In a second phase of the study the objectives were enlarged to include experimentation with new flow rate measurement devices and the development, fabrication, installation, and testing of a totally automatic unit which requires no operator computations and has a timer and printer for recording the pump efficiency data.

This project report describes the pump efficiency monitors that were built as well as their installation, testing and evaluation.

CHAPTER II

WATER WELL PUMP EFFICIENCY MONITOR UNIT COMPONENTS

Overall System

Determining water well pump efficiency requires the measurement of three quantities: The flow rate, Q, in cubic feet per second (CFS); the pump lift, E_p, in feet (FT); and the input power, P_{in}, in kilowatts (KW) are shown in Figure 1. From these quantities the pump efficiency, E, in percent can be easily calculated from:

$$\text{Pump Efficiency} = E = \frac{P_{out}}{P_{in}} (100) \quad [\%] \qquad (1)$$

where

$$\text{Output Power} = P_{out} = 0.0846\ QE_p \quad [KW] \qquad (2)$$

$$\text{Pump Lift} = Ep = H + \frac{V^2}{2g} + 2.31\ (P_L - P_B) \quad [FT] \qquad (3)$$

$$\text{Pipe Velocity} = V = Q/(A_L) \quad [FPS] \qquad (4)$$

A_L = delivery pipe internal area [SQ FT]

P_L = delivery pipeline pressure [PSI]

P_B = bubbler line pressure [PSI]

$\Delta P = P_L - P_B$ = lift differential pressure gage reading [PSI]

H = vertical distance from center of delivery line pressure gage to the bottom end of the bubbler tube in the well

The computation can be easily done by an untrained person using an inexpensive hand held calculator by following a simple set of instructions.

While the overall concept of pump efficiency measurement is simple, some of the parameters may be either difficult or costly (or both) to measure in existing pump installations where provision has not been made beforehand for the necessary instruments. Ideally, the measurement should be done with inexpensive, portable equipment that requires no alterations in the system, little time to set up and also requires little training to operate. Such ideal conditions are never met in practice--especially at low cost. There are always tradeoffs to be considered; between portability and permanence, among accuracy, precision and cost; between summer and all season operation; between systems requiring piping alterations and those that are non-invasive; and between automatic and manually operated systems, etc. Actually, cost is a prime consideration in all the tradeoffs listed above as well as others not mentioned.

Usually the measurements of pump efficiency has required the use of several special purpose tools and instruments by a highly trained expert over several hours time for each measurement. The technology may now be at hand to package the required instruments

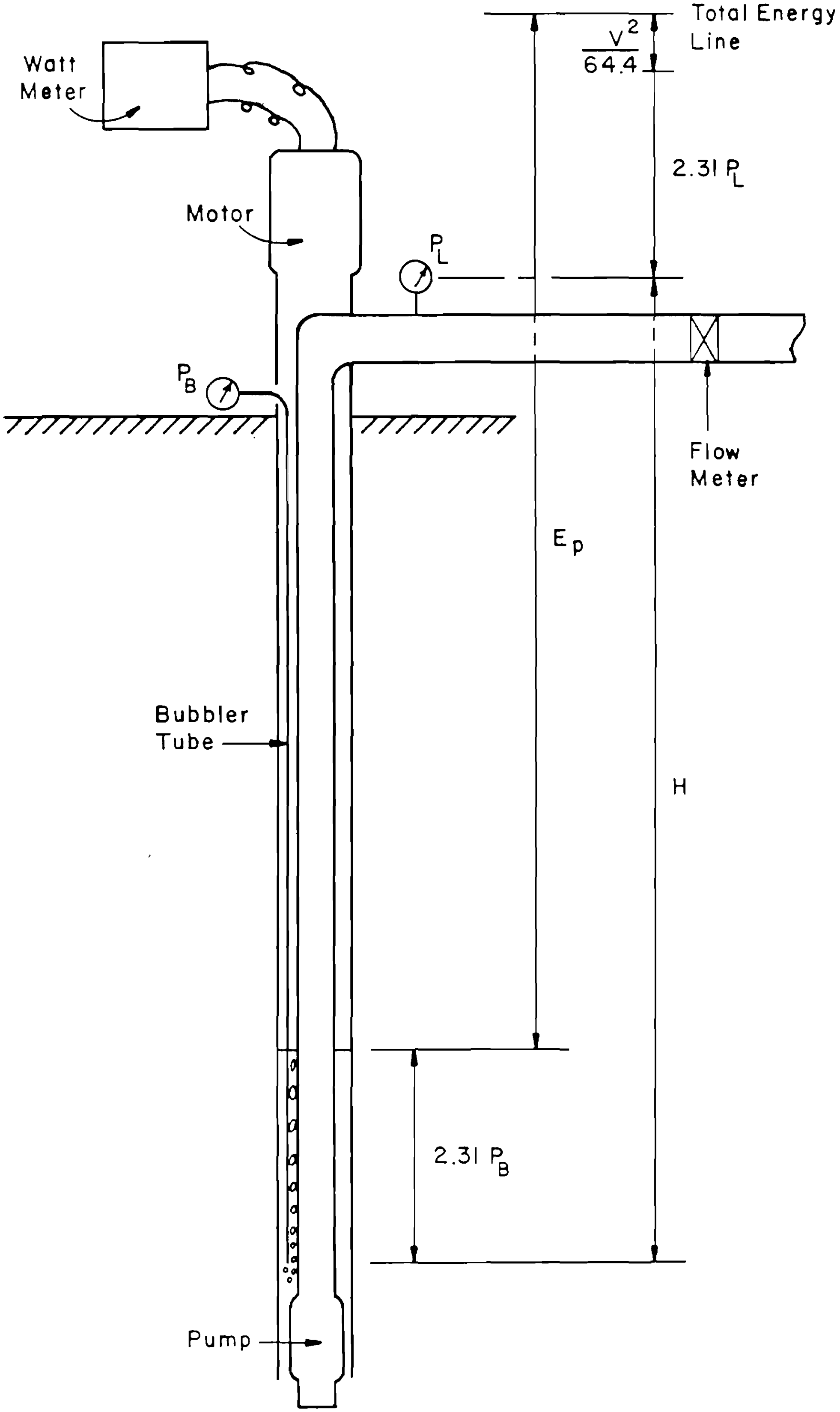


Figure 1. Pump efficiency measurement system components.

for pump efficiency measurements in one box at a mass production price low enough to be attractive to the pump owner. Installation and checkout should still be done by an expert, but the system could be attractive to the owner provided operation was either automatic or required only a semi-skilled, non-technical person for routine use.

In this part of the report the major components of the pump efficiency monitor unit are discussed, the various alternative devices are described and those selected for use in the prototype production models are given.

Flow Rate Measurements

Devices considered for measuring the flow rate were pitot tube devices, ultrasonic flow meters, other miscellaneous commercial flow meters (such as orifice plates, venturi meters, propellor meters, magnetic meters, etc.) and experimental equipment using injection of salt, dye, heat, or some other tracer to measure the flow rate.

Pitot tube devices. These instruments consist of a special tube inserted into the pipe. Inside the tube are two separate chambers. From one chamber one or more holes exit in the upstream direction and from the other chamber a hole exits downstream. The difference in pressure between the upstream and downstream ports is related to the velocity in the pipe by:

$$V = K \sqrt{\Delta h_w} \qquad [\mathrm{FPS}] \qquad (5)$$

where Δh_w is the pressure difference between the two ports (usually measured in inches of water). K is a constant depending on the location of the ports, the shape and size of the tube, the size of pipe, kind of fluid, the shape of the velocity distribution, the Reynolds number and back pressure conditions. For standard conditions K is determined by calibration done by the manufacturer. For standard installation with a straight, uniform approach pipe of at least 10 diameters upstream, the manufacturer's K will give good results. For locations that are non-standard (low downstream pressure, nearby elbows, valves or branches closer than 10 diameters upstream) the pitot type meter must be calibrated in place to give accurate measurements.

Many brands of pitot tube devices are available. The Utah Water Research Laboratory has used and calibrated many of these, such as Accutubes, the Annubars and Collins meters. An Accutube and an Annubar were selected for use with two of the units developed by this project. They were calibrated at the UWRL for standard approach conditions.

Pitot tube meters have the advantages of availability and low cost, but the disadvantage of requiring a hole to be drilled in the pipeline and a threaded fitting must be welded in place.

Ultrasonic meters. These meters are a relatively new development in flow measurement technology. While early models were quite expensive, costs have come down and reliability and precision have improved. Two types are commonly available from many manufacturers--the dual path and the doppler strap-on types.

The dual path ultrasonic meter requires either a special pipe spool with transducers already installed or the two transducer mounts must be welded to the existing pipe diagonally across along a line at 45° from the centerline. Ultrasonic signals are beamed from one transducer to the other in both upstream and downstream directions. The downstream signal is speeded up by the flowing water and arrives early while the upstream signal arrives late. Comparison of the travel times enables computation of the flow velocity. The required circuits are complex and expensive and installation costs are high but the device gives accurate and precise results with good reliability in both clean and somewhat dirty water. Because of the meter costs and the permanent installation required, this meter type was not considered appropriate for most pump efficiency units where portability, low cost and ease of installation were needed.

The doppler type strap on meter was better suited for many pump efficiency measurements. This unit will not work with completely clear water, but must have a small amount (about 5 percent) of sediment particles, air bubbles or intense, fine scale eddies present in the water. Only one transducer unit is required and it is attached with tape or a strap to the outside of the pipe with a layer of silicone grease between transducer and pipe. An ultrasonic frequency signal is produced by the meter unit which travels through the pipe wall and is directed upstream into the water. There the sound penetrates into the flow and then is reflected back by the particles of air or sediment and is at the same time transported downstream. Due to the well known doppler effect, the frequency of the reflected beam will be higher than the frequency of the transmitted signal. The higher the pipeline velocity, the greater the frequency change. This provides a way to compute the pipeline velocity.

When too few particles are present to give a useful reflected signal most meters display a warning that the signal levels are too low to be reliable. Then air or sediment must be added upstream to the flow if a successful measurement is to be made.

A portable doppler type unit was rented from Polysonics for testing to see if such a meter was suitable for use in a pump efficiency monitor. Measurements of flow in eight wells were made. A summary of the test wells and the results are given in Table 1.

Although signal levels were often marginal in the clean water without air injection, the results were promising enough to justify purchase of a unit.

One portable unit marketed by Bestobel (Model P-12) in Great Britain sells for about $2,000 in this country. A P-12 was acquired and further testing confirmed the conclusions drawn earlier as follows:

(1) If the pump is set within 50 feet of the ground level, air injection is not necessary for a good measurement. Entrained air and intense eddies give adequate reflection for the measurement.

(2) if 10 diameters or more unobstructed approach distance is <u>not</u> available, the meter will likely give an incorrect flow rate due to the abnormal velocity distribution in the pipe. In this case an in-place field calibration of the unit should be done against some other flow measurement device.

Where air injection is needed, it can be supplied by a small, low cost ($20) 12 volt air compressor and power supply. A small storage tank with pressure switch allows the compressor to run intermittently.

<u>Other flow meters</u>. Many other flow meters are available for permanent installation. Most require modification of the piping system and are thus not readily portable. Venturi meters, orifice plates, propellor meters, etc., belong in the group. Magnetic meters were once large and bulky but now are smaller and lighter. Most are built into special sections of pipe and thus require modification of the pipe system. However, some magnetic meters require only the insertion of a small diameter probe into the pipe and are just as easily installed as a pitot type meter, but are more costly.

<u>Tracer methods</u>. A tracer injected into a flow can be used to measure velocity by measuring the time to move a fixed distance. Thus a velocity

Table 1. Doppler ultrasonic meter tests on wells in Cache Valley.

Well Identification	Signal Strength	Would Air Injection Be Required?	Unobstructed Upstream Distance	Depth to Pump (ft)
UWRL Turbine Pump	High	No	> 10 Diameters	10
Drainage Farm Booster	High	No	∿ 5 D.	4
Crockett Ave., Logan City	Low	Yes	∿ 4 D., Unstable	>130
Smithfield Irr. Co. (150 W. Center)	High	No	> 5 D., Very Stable	<50
Smithfield Irr. Co. (450 S. 2nd W.)	High	No	> 15 D, Stable	<50
Lions Lodge Well	Low	Yes	∿ 5 D., Unstable	>100
Smithfield City Well (Ballpark)	Begins High, Later Low	No Yes	Entrained air gives stable signal at first but not good later	Unknown
Logan City, 7 N. 6 E.	Low	Yes	∿ 6 ft, Very Stable	Unknown

measurement becomes a matter of counting elapsed time. Since a counter/timer unit had been developed to measure power input, some experiments with tracers were conducted to see if a low cost tracer/flow meter could be developed.

The concept was tried out first using dye injection in a transparent section of pipe. A TV camera recorded the movement of the cloud past two lines inscribed around the pipe at a known distance apart. Using the built-in frame by frame advance system, the elapsed time was measured. The system was obviously not suitable for installation in a municipal or irrigation piping system, but did give some valuable insights into the design and operation of the tracer injection system.

The next tracer used was common salt water. Simple probes signaled passage of the tracer cloud with a rise in conductivity. A counter gave elapsed time between signals from the probes. However, because of understandable objections to adding salt to drinking water or irrigation water, this method was abandoned.

The last tracer tried was hot water. There usually is no objection to adding a little hot water to the flow, but problems in finding sensors to detect the passage of the warm cloud were formidable. When sensor and circuit development costs became too great, attempts to use a tracer technique for flow rate measurement were abandoned.

Pumping Lift Measurement

The pumping lift is the difference in elevations of the total energy line at the inlet and outlet of the pump as illustrated in Figure 1.

Bubbler tube. The pumping lift, E_p, in a pumped well can be most conveniently measured by means of a bubbler tube and a differential pressure gage. A bubbler tube is a small diameter fixed pipe installed in the well so that an end is always below the water surface in the well. The upper end is connected to a pressure gage and a source of air so that a small amount of air can be forced out the lower end a bubble at a time. Pressure, P_b, in the bubbler tube then depends on the depth of the lower end below the water surface. By connecting the bubbler tube to the low side of a differential pressure gage and the delivery line to the high side, the pumping lift is then given by Equation 3 where P_L-P_B is the reading of the differential pressure gage in psi.

Every water well should have a bubbler tube installed at the time the pump is set in the well, but most wells are not so equipped. Fortunately it usually is possible to add a plastic (Tygon) tube to the well at a later date. This can be done by attaching some small segments of articulated weights (about 1/2 lb is sufficient for Tygon tubing) to the end of 1/4 inch plastic tubing which is then lowered down the annular space between the casing and the delivery line in the well. The end of the tubing should be far enough below the water surface so that the bubbler line is always submerged. Purpose of the segmented weights is to allow it and the tubing to be threaded through the small diameter access hole usually found in the base plate of the motor. Stretching of the Tygon tubing was experimentally found to be non-significant compared to other inaccuracies in the system.

Due to irregularities in the hole alignment, the tubing sometimes becomes stuck between casing and delivery line. When this happens it sometimes helps to turn the pump on and off. This shakes the pump column and often frees the bubbler line so that it will slide on down the hole.

Low cost air supply. Commercial bubbler tube supply units are available.

These consist of a high pressure tank for air storage and a flow controller which releases the air in at a very slow rate. For this project another approach was developed. Air was supplied by a small, inexpensive air compressor for emergency inflation of automobile tires. The compressor delivers air to a small pressure tank and is turned on and off as needed by a pressure controller. Air from the tank is controlled and measured into the bubbler line by a low cost tapered tube flow meter. A flow of 0.5 to 1.0 SCFH (standard cubic feet per hour) is sufficient for the bubbler tube and can be easily supplied by the small compressor for long periods of time. Furthermore, air for injection into the pipeline for the ultrasonic doppler flow meter measurement can be supplied by the same system.

Input Power Measurements

Reading the wattmeter manually. Electrical wattmeters measure energy consumption by using a rotating disc in an electrical field. The strength of the field and therefore the rate of rotation of the disc (power) is directly proportional to the product of the applied voltage and the resultant current. The shaft of the disc connects to a set of gears which turn pointers to indicate the energy consumed in kilowatt-hours. To determine the power or rate of energy consumption all that needs to be done is first determine the meter constant (K_h) which is generally printed somewhere on the face of the meter and then measure the time required for a revolution of the disc. This is easily done with a stop watch since the disc has a short black stripe on it thus enabling an observer to determine when a revolution has occurred. Units of K_h are usually watt-hours per disc revolution. To improve the accuracy of measurement, it is best to time the disc for 10 revolutions. Since units if K_h are watt-hours per revolution and disc revolution measurement is in seconds, it is necessary to multiply the resulting number by 3600 to find the correct power in watts. An example should help to explain this measurement:

Suppose the meter K_h = 46.3 and the disc made 10 revolutions in 15 seconds. The power consumption would be

$$P_{in} = 46.3 \times \frac{10}{15} \times 3600$$

$$= 111.12 \text{ watts or } 111.12 \text{ kilowatts}$$

This number would then be substituted into Equation 1 to find the pumping system efficiency.

Semi-automatic power measurement. Using a regular wattmeter to determine the instantaneous power requires a measurement of the rate of rotation of the wattmeter disc. The power can then be found by using the K_h factor printed on the meter face. When automating power measurement it is convenient to count the time for 1 revolution. Then

$$\text{Watts} = (3600\ K_h)/M$$

where

$$M = \text{sec/rev}$$

To evaluate M it would be necessary to have a counter which counts seconds during one revolution. As an alternative, since 60 cps is conveniently present, the number of 60 cps cycles which occur during one revolution could be counted. This number will be 60 times M and the equation

$$\text{Watts} = \frac{(60)(3600)K_h}{60\ M} = \frac{216{,}000\ K_h}{C}$$

or

$$KW = \frac{216\ K_h}{C} \qquad (6)$$

where C is the number of 60 cps cycles in one revolution. Some meter installations have a current transformer in the circuit. If so, it will produce a multiplying factor on K_h. The factor is stamped on the coil and usually is between 2 and 10. For a semi-automatic monitor system, the monitor unit will count and display the factor C. The operator need only obtain K_h from the meter face, read the displayed count and substitute into the above equation.

The semi-automatic system to accomplish the power measurement is shown in the schematic diagram of Figure 2. In order to use this system it is necessary that the power company install a switch on the meter. This is a standard accessory and can readily be added to any power meter for about $500. This switch (one type is called a D-52 pulse initiator) will briefly close once for each revolution of the meter disc and thus facilitate the required measurement.

The circuit functions as follows: The D-52 switch sends a + signal to 4098-A through a 4093 Schmidt Trigger NAND gate. The output of 4098-A does two things, 1) toggles the 4027 (through 4098-B) and 2) produces an output (reset) pulse out of 4093 pin 10, if the 4027 $\bar{Q}$ line is high at the time. If the 4027 $\bar{Q}$ line is low, no reset pulse will be produced. If a reset pulse is produced, the counter is reset and the display goes to 0. The rising edge of the $\bar{Q}$ pulse from 4098-B toggles the 4027 whose Q line enables 4093 pin 13 so that the 60 Hz pulses on pin 12 are passed on to the counter. The counter accumulates 60 cps counts until the next closure of D-52 which repeats the above sequence except that with 4027 $\bar{Q}$ high there will be no 60 N pulses to the counter so it just holds the count obtained at the end of the first revolution.

The waveform at various indicated points in the circuit are shown in Figure 3. It will be seen that the display counts during one disc revolution and displays during the next. This affords the operator sufficient time to observe and manually record the count to be entered into the equation. For improved accuracy, if power fluctuates, it is recommended that several sequential readings be recorded and the average taken.

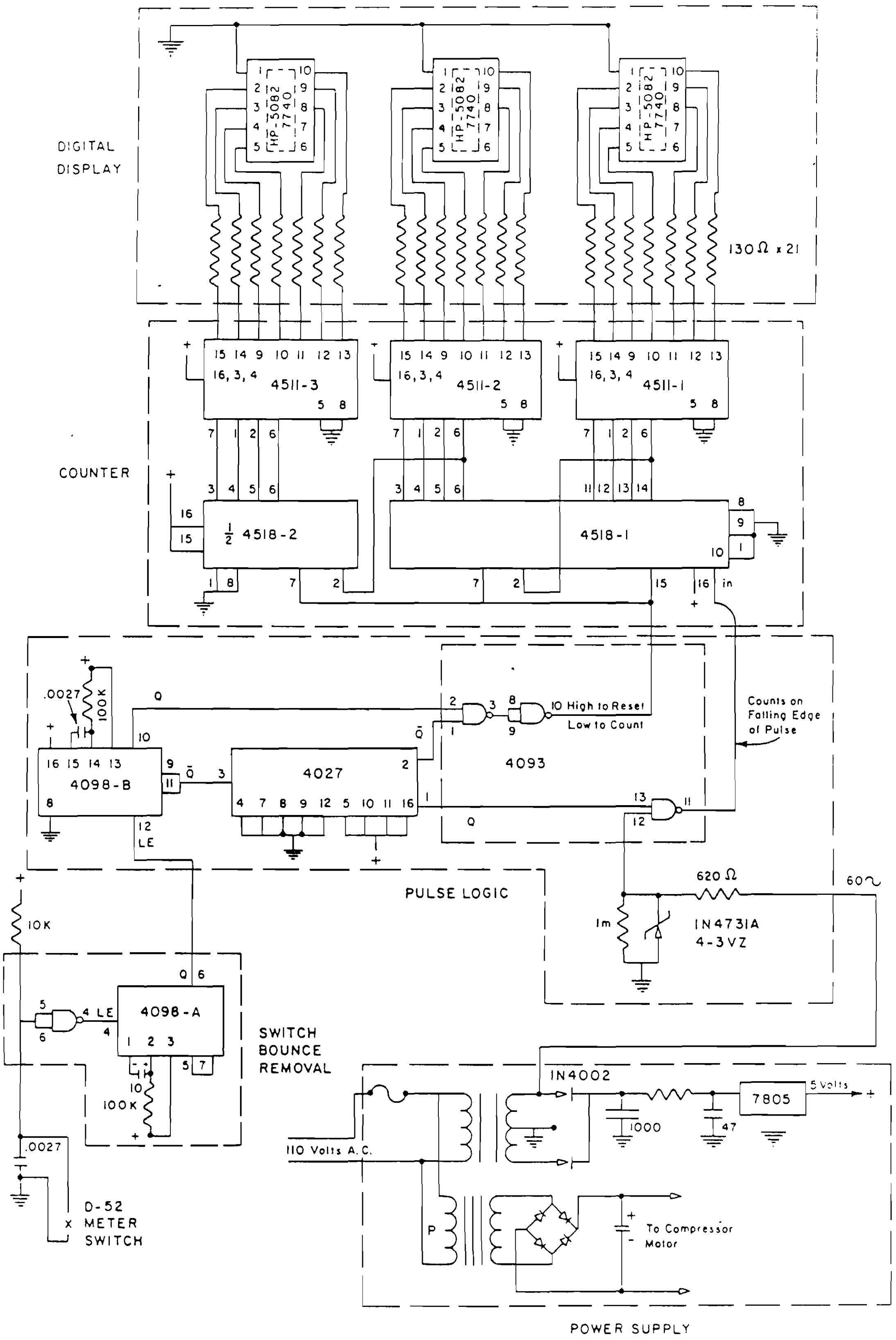


Figure 2. Counter/timer circuit diagram for input power measurement.

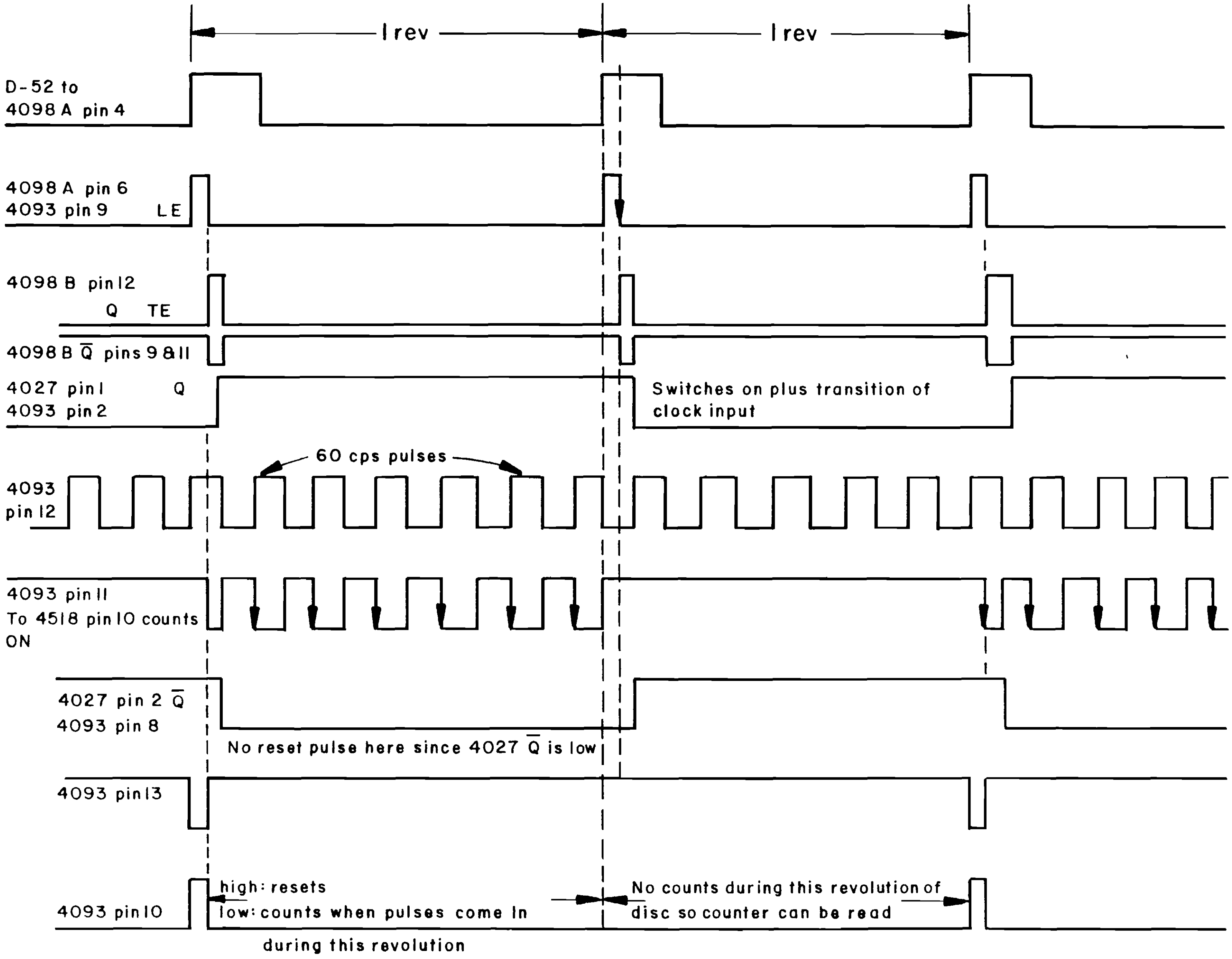


Figure 3. Input power measurement counting sequence diagram.

CHAPTER III

LOW COST SEMI-AUTOMATIC MONITOR DEVELOPMENT

The semi-automatic pump efficiency monitor development began with an experimental prototype model which was followed by two improved production models.

Prototype Model

The prototype monitor unit had the following components:

- Power supply to make available 12 v. DC for the compressor and the 5 v. DC for the timer circuits.
- Compressor, air tank and controls to supply air for the bubbler tube and for air injection if the ultrasonic flow meter was used.
- Accutube and differential pressure gage (0-10 inches water) to determine the pump discharge rate.
- Pump lift differential pressure gage to measure pumping lift (0-60 psi).
- Counter-timer and display to measure the number of 60 cps counts during one revolution of meter disc.
- Miscellaneous wiring, switches, tubing, bleed valves, air flow meters and control valves.
- Hand held calculator for efficiency computations.

Most of the components were roughly mounted in a carrying case for convenience of transport. The prototype unit was first built, installed, tested and evaluated for ease and accuracy of operation on one of the pumps at the Utah Water Research Laboratory. Later in the spring of 1980 it was installed on the Kimberly, Idaho, city well No. 1 where it operated intermittently for over two years until it was dismantled and used for parts when the totally automatic unit was developed. Site parameters for the Kimberly No. 1 well were as follows:

Delivery line I.D. = 8.225 inches.

Approximate discharge = 800 gpm. Measurement by means of an "Accutube" pitot device and a differential pressure gage or by a Bestobel Ultrasonic Meter.

Approximate line pressure = 34 psi.

Vertical distance from pump lift gage to bottom of the existing bubbler tube = 228.3 ft.

Power meter is equipped with D-52 pulse initiator switch.

Power meter factor is 57.6 and current transformer factor = 2.

The delivery pipe has a check valve and a 90° elbow, then a straight piece of pipe about 10 diameters long before the pipe goes underground. The set of operating instructions shown in Table 2 were prepared based on the site parameters and monitor characteristics.

While the monitor unit was set up at UWRL, several persons were invited to

Table 2. Pump efficiency monitor instructions for prototype unit installed at Kimberly City Well No. 1.

1. Turn on master switch "A". Compressor will start and pump air tank up to 30 psi (gage "C") and shut off.

2. Close bypass valve below gage "B". Read gage "B" and record the differential pressure head, Δh_w (inches of water) after the gage stabilizes.

3. Turn on bubbler tube air flow gage "D" until indicator shows 1.0 SCFM (ball at red line). The ball will slowly drop as the pressure in the air tank goes down. Thus, small adjustments may be needed until gage "E" stabilizes. Read gage "E" and record pressure ΔP (psi) after gage stabilizes and reaches its lowest point.

4. Note the 3 digit electronic time display "F" and record the average of at least 5 readings (T).

5. Calculate pump efficiency, E, from equations shown below.

6. Record the reading from the pressure gage on the discharge pipe.

7. At end of monitor test:
   (a) Turn off air flow gages
   (b) Turn off master switch "A"
   (c) Open bypass valve beneath gage "B"
   (d) Turn off and stow calculator

8. Equations for individual calculations:

   (a) Velocity, ft/sec: $V = (1.548)\sqrt{\Delta h_w}$

   (b) Discharge: $Q_{cfs} = 0.369V$; $Q_{gpm} = 0.369\ (449)\ V$

   (c) Pumping head or total lift, ft: $E_p = (2.31)(\Delta P) + 228.3 + V^2/64.4$ $(V^2/64.4 = 0.35 \text{ ft})$.

   (d) Power out, (KW): $P_o = (0.0846)\ (Q \text{ in cfs})(E_p)$

   (e) Power in, (KW): $P_i = 24883/T$

   (f) Pump efficiency in percent: E = Power out (100)/Power in

9. Alternate method to obtain V in ft/sec: Read directly from the Bestobel meter "G" while injecting air into the pump delivery line by turning on air flow gage "H" to 1 SCFH.

use the monitor to determine the pumping system efficiency. Some were engineers, some were shop technicians and some were students. With just a few minutes to study the written instructions but with no other training with the unit, each person was able to successfully complete an efficiency measurement. While such persons who were not familiar with the monitor unit could use it to determine pump efficiency, they probably could not recognize if something was wrong with the unit, and could not cope with malfunctions or diagnose the cause of failures. Trained persons would still be needed to make periodic inspections of the monitor to see that it was in working order.

Since the prototype unit was installed inside a pump house, there was no need to weatherproof it or take special care to guard against freezing conditions in the wintertime.

Table 3 shows some typical efficiency values for the Kimberly City Well No. 1. The data indicate a drop in efficiency in 1982.

Production Models

One production model was a low cost semi-portable unit and the other was a medium cost, portable unit. Both units were carefully packaged in a carrying case for protection from the weather and from vandals and for convenience when transporting them.

Low cost unit. This unit is shown in Figure 4 and has the following components:

Power supply for the compressor.

Compressor system to supply air to the bubbler tube.

"Annubar" and differential pressure gage to measure pump discharge.

Bubbler tube pressure gage.

Miscellaneous wiring, switches, tubing, valves and air flow meter.

Hand-held calculator with stop watch capability for timing the disc and computing the efficiency.

The low cost unit was initially installed on a well belonging to Gary Nebeker located 1/2 mile south and 1/2 mile east of N3000, E4300 near Kimberly. Site parameters are as follows:

100 H.P. pump.

Delivery line I.D. = 8.06 inches.

Approximate discharge = 640 gpm. Measurement by "Annubar" pitot tube device.

The line pressure was not measured since the pump delivery is into an open ditch after just 14 ft of pipe. Bubbler tube pressure was measured by pressure gage.

No bubbler tube was in the well, but a plastic bubbler line was successfully installed. Vertical distance from the end of the bubbler tube to the center of the delivery line at the ditch is 451 ft.

The power meter was not equipped with pulse initiator switch so the disc rotation was timed by the calculator/stop switch.

The operating instructions for the unit are given in Table 4 and a typical measurement in Table 5. Approximate production cost of the unit was $2,250 not including development costs. Mass production and purchasing would reduce this somewhat, but manufacturers profit would make the selling price near the above amount.

Medium cost unit. The unit is shown in Figure 5 and has the following components:

Table 3. Pump efficiency data--Kimberly City Well No. 1.

Date	Discharge Flow Rate (gpm)	Power (Kw)	Pumping Head (ft)	Pump Efficiency (%)
1980				
6/10	790	67.6	283	62.2
6/11	803	67.6	285	64.0
7/30	807	67.4	285	64.3
1981				
6/11	807	68	283	63.1
6/19	790	68	284	62.8
7/16	803	67	286	64.5
7/24	799	67.4	284	63.2
7/30	799	67.4	284	63.2
8/20	798	67.4	284	63.3
9/10	798	67.2	282	63.0
9/23	808	67.6	277	63.9
1982				
5/27	726	68.1	285	57.2
6/11	726	67.8	290	58.6
7/2	734	67.2	284	58.3
7/9	734	67.8	281	57.3
8/6	726	67.4	284	57.7

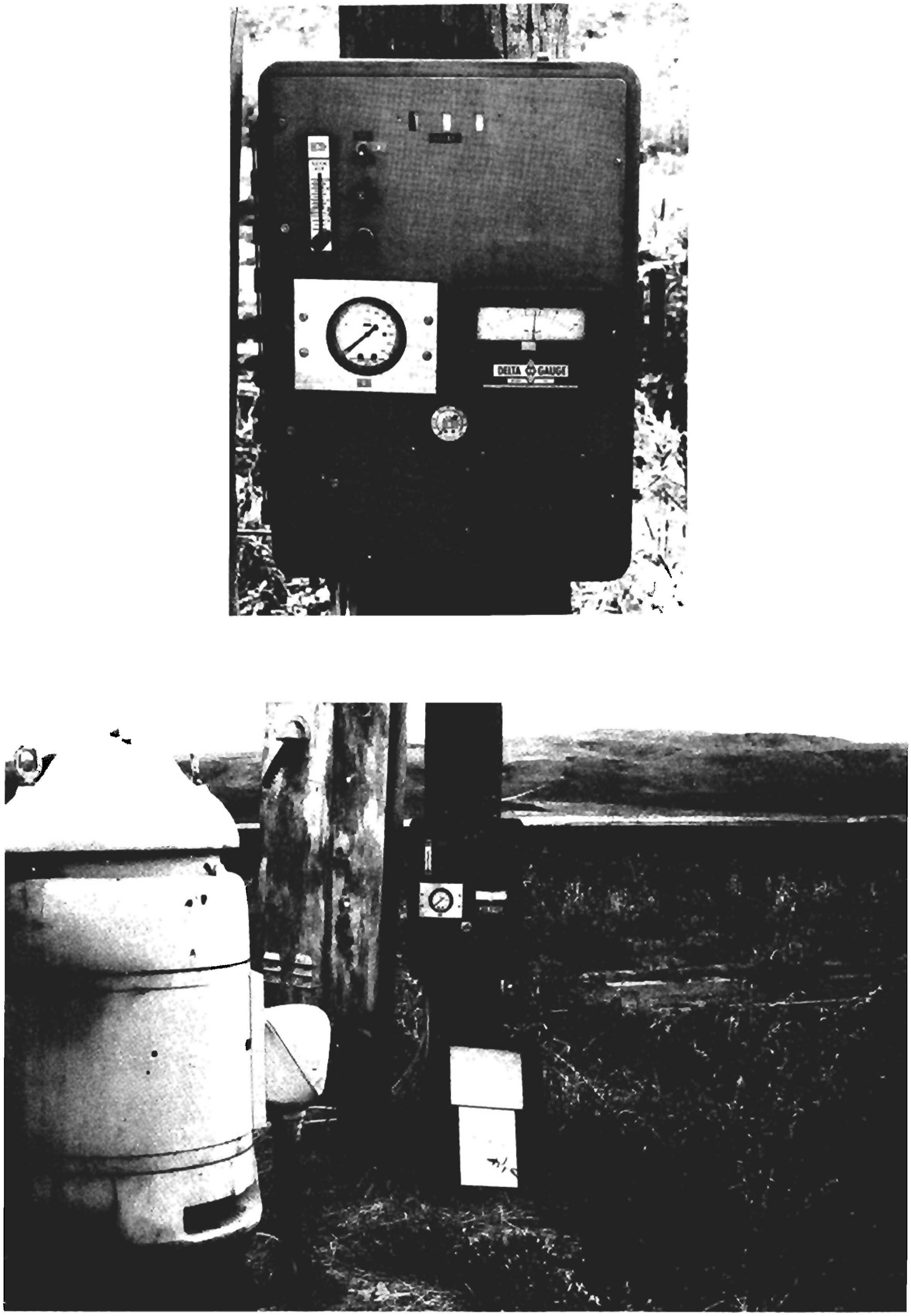


Figure 4. Low cost monitor unit.

Table 4. Pump efficiency monitor instructions (Gary Nebeker Well).

1. Remove front cover of monitor box. Attach extension cord between the monitor box and the 110 V outlet on bottom of the pump starter box. Turn on master switch "A". Compressor will start and pump air tank up to 40 psi (gage "b") and will shut off.

2. Open both of the small valves on top of the flow sensor in the pump delivery line. These control the flow through the 1/4 inch tubing connecting the monitor box and the flow sensor. Both 1/4 inch lines must be completely full of water. Close the bypass valve connecting the two 1/4 inch tubes where they enter the monitor box.

3. Turn on bubbler tube air flow gage "C" until indicator shows 1.0 SCFH. Record lift pressure, p, from gage "D" in psi after the gage stabilizes and reaches its highest point.

4. Record differential pressure, Δh_w, from gage "E" in inches of water after the gage stablizes at its highest reading.

5. Familiarize yourself with the operation of the calculator as a stopwatch. Time the seconds, T, required for 10 revolutions of the power meter disc. Take an average of at least 3 readings of T and record it.

6. Calculate the discharge, pumping lift, power output, power input, and the efficiency using the equations below.

7. At the end of the efficiency test:

   (a) Turn off air flow gage "C".

   (b) Close both tubing valves on top of flow sensor on pipeline.

   (c) Open bypass valve between tubing where it enters box.

   (d) Turn off master switch "A".

   (e) Stow calculator.

   (f) Remove extension cord and replace monitor box cover.

Velocity, V, in feet per second $V_{fps} = 1.526 \sqrt{\Delta h_w}$

Equations:

(a) Discharge, Q $\quad Q_{cfs} = 0.541 \sqrt{\Delta h_w} \quad Q_{gpm} = 243 \sqrt{\Delta h_w}$

(b) Pumping Lift, E_p $\quad E_p = 451.3 - (2.31)(\Delta P)$

(c) Power Output, P_o $\quad P_o = (0.0846)(Q_{cfs})(E_p)$

(d) Power Input, P_i $\quad P_i = 1{,}728/T \quad$ T = Time in seconds for 10 revolutions of the disc

(e) Efficiency (%), E $\quad E = (P_o/P_i)\ (100)$

Table 5. Pump efficiency monitor data sheet (Gary Nebeker Well).

Date (1981)	Bubbler Pressure ΔP psi	Differential Pressure Δh_w inches H_2O	Time for 10 Revolutions Seconds	Flow Rate Q cfs	Pumping Lift E_p ft.	Power Output P_o kw	Power Input P_i kw	Pump Efficiency E %
19 June	13.6	6.9	20.5	1.42	419.9	50.4	84.3	59.8
16 July	7.1	6.7	20.9	1.40	434.9	51.5	82.7	62.3
24 July	5.6	6.4	21.0	1.37	438.4	50.8	82.3	61.7
31 Aug.	13.0	6.9	20.6	1.42	421.3	50.6	83.9	60.3
10 Sept.	13.5	7.0	20.4	1.43	420.1	50.8	84.7	60.0
23 Sept.	12.6	6.8	20.3	1.41	422.2	50.4	85.1	59.2

Figure 5. Medium cost monitor unit.

Power supply for compressor and timing circuit.

Compressor system for the bubbler air and injection air for the Ultrasonic flow meter.

Bestobel Ultrasonic flow meter to measure pump discharge.

Pump lift differential pressure gage.

Counter-timer and display to measure the 60 cps counts during a revolution of the disc.

Miscellaneous wiring, switches, tubing, valves and air flow meters.

Hand held calculator to compute efficiency.

The medium cost unit was initially installed on a well belonging to Kevin Stanger located 1/2 mile south of the Kevin Stanger home at N3200, E4000 near Kimberly. Site parameters are as follows:

Delivery line I.D.= 10.5 Inches

Approximate discharge = 900 gpm. Measurement by Ultrasonic flow meter.

Approximate line pressure = 75 psi

From the pump there was 2 1/2 ft of delivery line, then a welded-in check valve, then 1 1/2 ft of pipe, followed by a 45° elbow and then only 3 1/2 ft before the delivery pipe went underground.

No bubbler tube was in the well but a plastic bubbler line was successfully installed. Vertical distance from end of bubbler tube to center of lift gage is 298 ft.

The power meter was equipped with a pulse initiator switch (charges by Idaho Power for this was $516).

The operating instructions for the unit are given in Table 6 and a typical measurement in Table 7. The efficiency is thought to be higher than is likely for the well. This is believed to be due to the extremely short line (2 1/2 ft) available above ground for location of the sensor for the Bestobel Ultrasonic flow meter. The check valve, elbow and short distance means the velocity is not distributed as it should be for a factory calibrated measurement. The meter could give accurate flows if the meter could be calibrated in place, but this was not possible without extra costs. Since the primary purpose of this work was to test the reliability and ease of operation of the unit, no effort was made to check the calibration of the meter in place. This should be done if accurate readings are required.

Cost of the medium unit was about $3,300 to which should be added cost of the pulse initiation switch.

Both production units were packaged in a weatherproof box. Both units had to be drained in the fall to prevent damage to the components by freezing. This is not a problem on an irrigation well, but additional "winterizing" work would be needed to keep the units located outdoors running in the winter. For winter operation, pressure taps must be replaced by a sensor ring such as those marketed by Red Valve Co. and shown in Figure 6. Thus, one sensor ring would be needed at each pressure tap location. The Nebeker well would need two (for flow measurement). The "flow" differential pressure gage would have to be replaced by two identical pressure gages of a type that would measure the pressure without much movement of fluid in the lines. The fluid in the lines between sensor rings and transducers would be anti-freeze. Stanger's well would also require two sensor rings on the lift differential pressure gage. The ultrasonic meter would need no winterizing. Costs per sensor ring would be about $300 or $600 for each unit.

Table 6. Pump efficiency monitor instructions (Kevin Stanger Well).

1. Remove front cover of monitor box. Attach extension cord between the monitor box and the 110 Volt outlet on bottom of the pump starter box. Turn on master switch "A". Compressor will start and pump air tank up to 100 psi (gage "B") and will shut off.

2. Open both of the small valves on top of the pump delivery line. These control the flow through the 1/4 inch tubing connecting the monitor box and the delivery pipe.

3. Turn on bubbler tube air flow gage "C" until indicator shows 0.5 SCFH. Record lift pressure, p, from gage "D" after the gage stabilizes and reaches its lowest point.

4. Turn on air injection flow gage "G" until indicator shows 2.0 SCFH. Turn on Bestobel flow meter "E" by pushing "On" button. After a short time the signal strength meter should read greater than 6 and the velocity meter will reach a maximum. Record the velocity, V, on data sheet. The meter will automatically turn off after 1 minute. Be sure the "Fluid Calibrate" dial is set at 0.5 and the "Noise Cancel" dial is full clockwise. Because of electrical interference from the compressor unit, read the flow meter only when the air compressor is not running.

5. Note the 3 digit electronic timer display "F". Record the average of at least 5 readings of T.

6. Calculate the discharge, pumping lift, power output, power input and the efficiency using the equations below.

7. At the end of the efficiency test:

   (a) Turn off air flow gages "C" and "G".
   (b) Close both tubing valves on top of pump delivery line.
   (c) Turn off master switch "A".
   (d) Turn off and stow calculator.
   (e) Remove extension cord and replace monitor box cover.

   Velocity, V, in feet per second from Bestobel flow meter

Equations:

(a) Discharge, Q $\quad Q_{cfs} = 0.601\ V \qquad Q_{gpm} = 269.8\ V$

(b) Pumping Lift, E_p $\quad E_p = 298.2 + (2.31)\ (p)$

(c) Power Output, P_o $\quad P_o = (0.0846)(Q_{cfs})(E_p)$

(d) Power Input, P_i $\quad P_i = 82{,}944/T$ $\quad$ T= Number of 60 cps counts in one revolution of the disc

(e) Efficiency (%), E $\quad E = (P_o/P_i)\ (100)$

Table 7. Pump efficiency monitor data sheet (Kevin Stanger Well).

Date (1981)	Lift Pressure P psi	Flow Velocity V fps	Timer Reading T	Flow Rate Q cfs	Pumping Lift E_p ft.	Power Output P_o kw	Power Input P_i kw	Pump Efficiency E %
19 June	71.3	3.6	822	2.16	462.9	84.6	100.9	83.8

Both units operated successfully for two summers at their initial installations. They performed consistently and reliably except for the flow measurement on the Stanger well as already discussed.

Both units could be operated by inexperienced people if they would take time to study and follow the given directions.

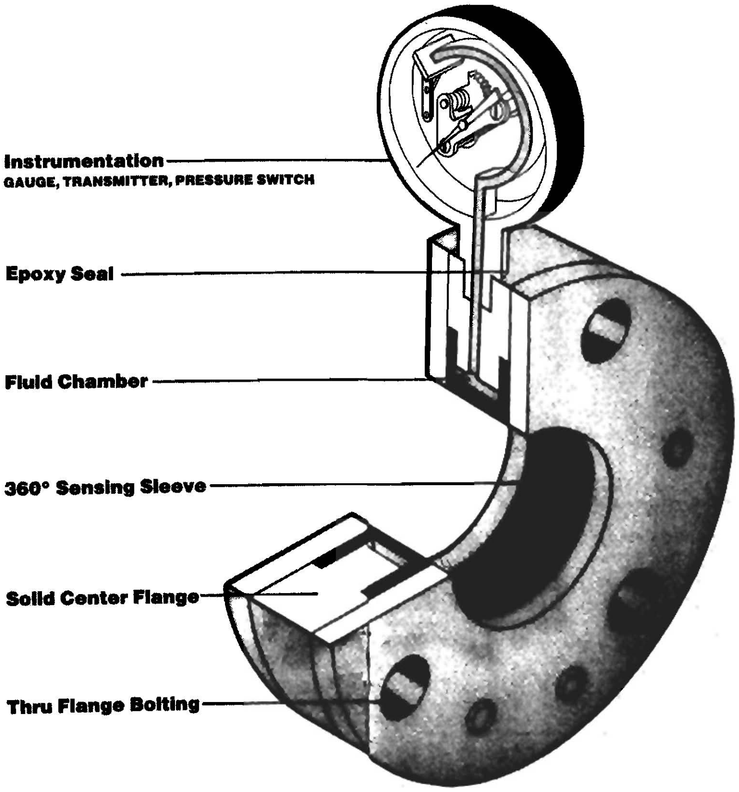


Figure 6. Sensor ring for winterized operation.

CHAPTER IV

FULLY AUTOMATIC MONITOR SYSTEM DEVELOPMENT

Concept and Capability

The fully automatic monitor system was developed under an extension of the original contract in response to the perceived need for a system that would not require an operator to do any part of the measurement, computations, or recording of the data. The objective was to produce a compact, semi-portable system which could initiate a measurement of pump efficiency at any preselectable time, measure and store all the necessary parameters, make the needed computations, and then both display and print the relevant information.

Initially the plans were to convert an available calculator or computer device to perform the tasks. Soon it became apparent that a unique, special purpose computer system could be developed just as readily which would have the added advantage of greater flexibility and reliability. The computer system chosen is based on the 8 bit Z-80A microprocessor.

Description of the Fully Automatic System

The fully automatic system was packaged in two cases as shown in Figure 7 which contain the following components:

Auxiliary equipment case.

Power supplies for compressor, transducers, and solenoid valves.

Compressor, air tank, and air flow controls to supply air for the bubbler tube.

Pump lift differential pressure transducer to measure pumping lift (0-100 PSID).

Accutube and differential pressure transducer to measure pump discharge rate (0-20 inches water).

Solenoid valves for protecting the flow transducers between measurements, bleeding accumulated air from the lines, and determining the zero flow condition.

Miscellaneous wiring, connectors, switches, bleed valves, etc.

Computer case.

Power supplies for computer, printer, clock, and other circuits and controls.

Computer to control operations, make calculations, and display and print the results.

Display module for Efficiency, Power In, Lift, and Flow.

Paper tape printer with choice of continuous or once a day readings.

Real time clock with initialization (setting) capability.

EPROM for programmable memory.

ROM for storing site data through switch selectable inputs.

Umbilical connection to auxiliary case.

The operations done by the monitor unit make the necessary measurements and

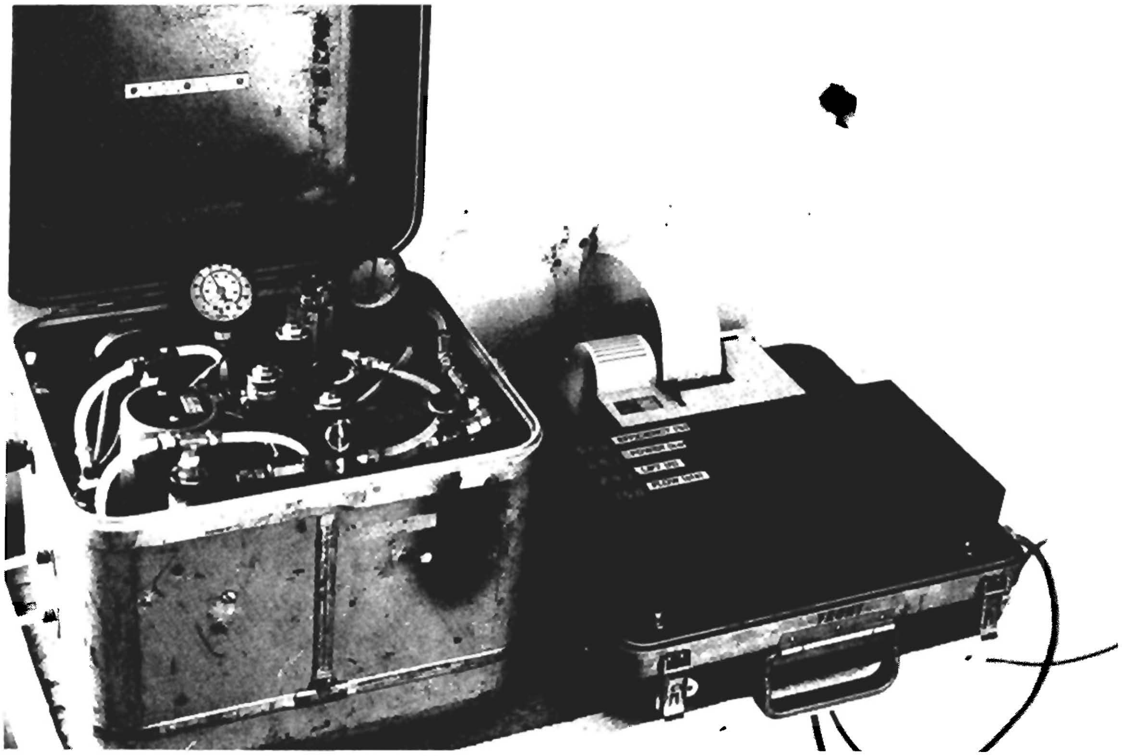


Figure 7. Automatic monitor unit.

then evaluate the pumping system efficiency using the following equation:

$$\text{Efficiency (\%)} = \frac{0.0846\ V\ A_L\ (H + \frac{V^2}{64.4} + 2.31\ \Delta P)}{\text{meter factor} \div \text{time for 1 disk rev.}}$$

where $V = 1.52\ \Delta h_w$, and h_w is the differential pressure head in inches of water.

The pitot tube device used to determine the flow rate requires the measurement of a small (about 10 inches of water) differential pressure in a pipe with a high line pressure (usually > 50 psi). The small differential pressure to be measured requires a sensitive transducer which is vulnerable to damage should a larger differential occur for any reason. Furthermore, air bubbles may accumulate in the tubing and this requires bleeding the air bubbles from the system. Finally, some electrical drift occurs in all transducers if given enough time and this requires some means of taking a "zero" reading as a reference for the measurement.

The pumping lift is usually large so a much less sensitive transducer is used. Only an occasional manual air bleed is needed to keep this transducer in operating condition.

Sequence of Events During Monitor Operation

The operation of the monitor system can best be described by listing the sequence of events which occur during a set of measurements. It is assumed that the monitor unit has been installed at a well site, that the real time clock has been set to local time, and the site constants have been loaded in the computer memory by following the instructions in Appendix A.

1. Begin a measurement upon a signal from a switch or from the real time clock.

2. Measure 10 revolutions of the power meter disk and compute and store the power input, P_{IN}.

3. Measure and store the lift pressure, ΔP.

4. Operate solenoid valves to protect the flow transducer between readings, to bleed air from the lines prior to a reading, and to make and record a "zero" reading of the transducer.

5. Measure the velocity differential pressure head, Δh_w, by reading the flow transducer and subtracting the zero reading. Then compute and store the velocity, V, in Equation 5.

6. Compute and store the pumping lift, E_p, in Equation 3.

7. Compute and store the flow rate, Q, in Equation 4.

8. Compute and store the efficiency, E, in Equation 7.

9. Display the Efficiency, Power In, Lift, and Flow Rate.

10. Print the well number, day, date, time, Efficiency, Power In, Lift, and Flow Rate.

11. Repeat the sequence above two more times to complete a set of three measurements.

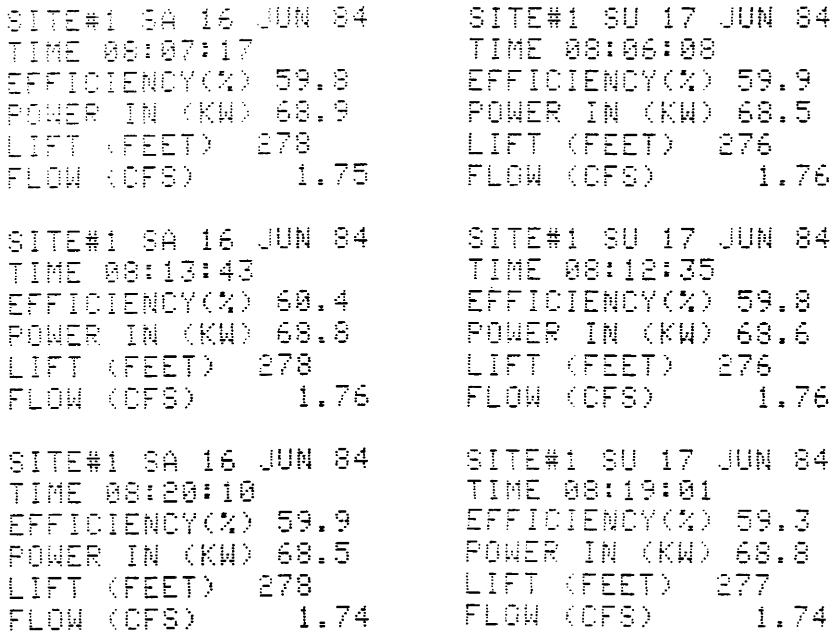
12. Wait for the signal to begin the next series of measurements (2 min to 24 hr as selected by setting the switch to "Continuous" or "24 hr").

Since the monitor unit is completely automatic in its operation, no instructions are needed for operation once it has been installed and set up by a qualified person. The experimental unit was not installed in a weatherproof box, however, and it must be given suitable protection in a shelter and kept above freezing temperature.

The automatic monitor unit was installed initially inside the pump house of the Kimberly City well where it operated successfully for two periods of several months each. Figure 8 shows typical data from the printer. Each time service was ended by failure of the same integrated circuit chip at the time of a power outage. Apparently a transient power surge damaged the chip. Protection of the unit with a constant voltage transformer or surge arrestor is recommended.

Once a week the air that accumulates in the line pressure transducer tubing should be bled out by slowly opening the bleed valve for a few seconds. Now and then the paper tape in the printer must be replenished and the printed tape record removed. Normally no other routine maintenance is needed.

A more detailed description of the monitor unit and its electrical circuits is given in Appendix A. Instruction for initial installation at a site, inputing the site parameters, setting the real-time clock, and starting up the unit are also given in Appendix A. The computer program that runs the unit is listed in Appendix B.



```
SITE#1 SA 16 JUN 84      SITE#1 SU 17 JUN 84
TIME 08:07:17            TIME 08:06:08
EFFICIENCY(%) 59.8       EFFICIENCY(%) 59.9
POWER IN (KW) 68.9       POWER IN (KW) 68.5
LIFT (FEET)  278         LIFT (FEET)  276
FLOW (CFS)      1.75     FLOW (CFS)      1.76

SITE#1 SA 16 JUN 84      SITE#1 SU 17 JUN 84
TIME 08:13:43            TIME 08:12:35
EFFICIENCY(%) 60.4       EFFICIENCY(%) 59.8
POWER IN (KW) 68.8       POWER IN (KW) 68.6
LIFT (FEET)  278         LIFT (FEET)  276
FLOW (CFS)      1.76     FLOW (CFS)      1.76

SITE#1 SA 16 JUN 84      SITE#1 SU 17 JUN 84
TIME 08:20:10            TIME 08:19:01
EFFICIENCY(%) 59.9       EFFICIENCY(%) 59.3
POWER IN (KW) 68.5       POWER IN (KW) 68.8
LIFT (FEET)  278         LIFT (FEET)  277
FLOW (CFS)      1.74     FLOW (CFS)      1.74
```

Figure 8. Typical printer tape.

CHAPTER V

SUMMARY

The Utah Water Research Laboratory of Utah State University has developed, tested, and evaluated four low-cost, pump efficiency monitors. The units are packaged for convenience in a carrying case(s) and can be installed permanently or used as portable units. The prototype and two of the simpler units require the operator to read some gages and then use a hand-held calculator to make some simple calculations to determine efficiency. One model uses a pitot tube device and the other an ultrasonic meter to measure flow rate. The final model is totally automatic in its operation. A timer turns the unit on at a programmed time and the unit itself makes all the measurements and calculations, displays the results, and also prints a permanent record. The unit can also be set for continuous operation. Costs of the units, not including development costs, are between $2,250 and $5,500 depending on the sophistication.

APPENDIX A

COMPUTING ELECTRONICS FOR THE AUTOMATIC PUMP EFFICIENCY MONITOR

This appendix describes the computing electronics for the automatic pump efficiency monitor. The accumulation of data from the velocity, pressure and kwh meter-timer peripheral transducers is accomplished via this unit and the computation of the efficiency of the pumping system is done using the following equation:

$$\text{EFFICIENCY (\%)} = \frac{P(\text{OUT})}{P(\text{IN})} \times 100 =$$

$$\frac{0.0846\ VA_L\left(H + \frac{V^2}{64.4} + 2.31\ \Delta P\right)(100)}{\text{meter factor} \div \text{time for 1 disk rev.}}$$

where

V = velocity of water in pipe (feet/sec) = $1.548\ \sqrt{\Delta h_w}$

Δh_w = velocity differential head (inches of water)

A_L = cross-sectional area of pipe (square feet)

H as indicated in Figure A-1, vertical distance from center of lift gage to the end of the bubbler tube (feet)

P_L = line pressure (pounds per square inch, psi)

P_B = bubbler pressure (psi)

ΔP = $P_L - P_B$ (psi) = lift pressure differential (psi)

The computer system is based on an 8-bit microprocessor, the Z-80A, which was chosen for its availability and copious documentation, ease of operation for the job specification, and the experience with the device.

Because plenty of power was available at the point of use, it was not necessary to base the electronics around a low-power c-mos microprocessor, suitable for battery operation and thus a standard Z-80A operating at 5 volts, with a 2.4576 MHz crystal clock was used.

The electronics accompanying the microprocessor, as found on the main board, and controlled by and/or supplying data to the Z-80A can be divided into the following main areas:

1. Reset and clock
2. Address/data/control bus buffering
3. Input/output, memory address decoding
4. CTC counter/timer circuits
5. PIO input/output circuits
6. Analog-to-digital conversion
7. RAM/ROM memory devices

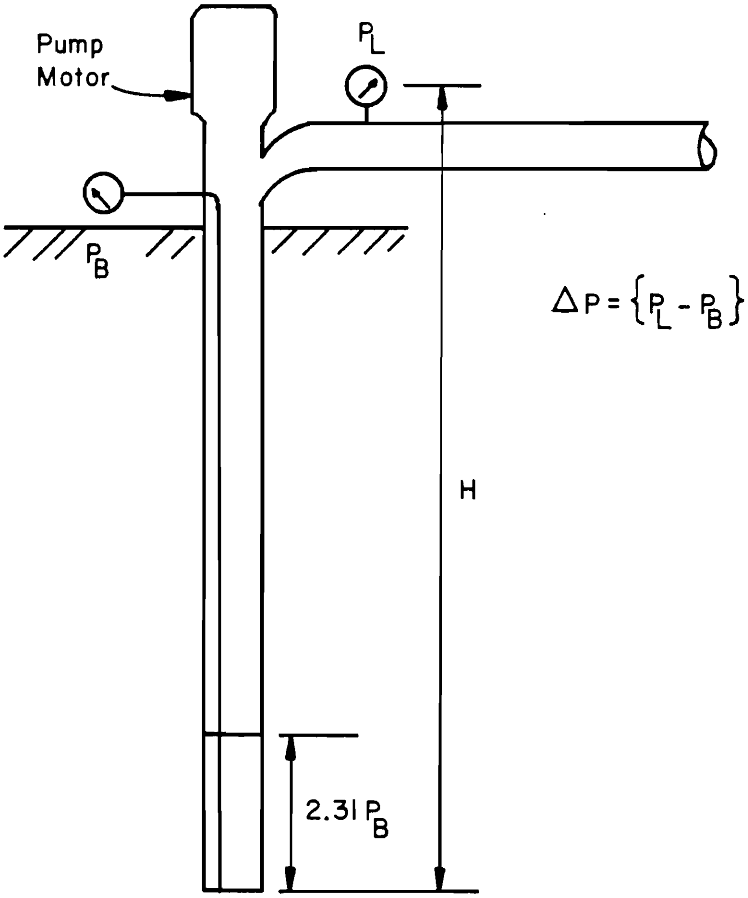


Figure A-1. Pump lift diagram.

8. Switched ROM devices

9. 7-segment display

10. RTC real time clock

11. Printer output

12. Compressor unit and secondary electronics

The above areas will be elaborated upon with reference to specific circuitry and basic properties that describe each section with respect to the others. The following overall system diagram, Figure A-2, serves to tie in each of the above sections to form the total computer system.

1. RESET and Clock

(a) The RESET function is a most necessary control in that once activated it stops the microprocessor's execution of instructions and loads the program counter within the Z-80A with 0000HEX, i.e., the lowest memory address. The program is written into an EPROM with a starting address of 0000HEX. The application of the RESET signal will interrupt the current sequence of instructions and force the program to be initialized, commencing at 0000HEX. The RESET (the condition is logic zero) is generated by power-on as well as by push-button momentary contact manual operation. The signal is also fed to the counter/timer circuits.

Upon power-on, the capacitor (47 microfarads in Figure A-3) is initially discharged and a logic 0 will appear on the RESET output for a fraction of a second. Once power is on a RESET can be obtained by the push-button momentary contact switch being depressed. The processor remains in the RESET state as long as the switch is depressed.

(b) The Z-80A requires a single phase clock only and can be run up to 4 NHz. To provide convenient divisions for the CTC timing sequences a 2.4576 MHz clock has been used as shown in Figure A-4 (note that 2.4576/256 = 9600 Hz, 9600/96 = 100 Hz, i.e., 100 pulses per second or a resolution of 1/100th of a second). For consistent execution time and for more precise timing for the CTC, a crystal controlled circuit is used.

The 330 ohm pull-up resistor satisfies the AC and DC clock signal requirements but a separate inverter gate section is used to drive the pull-up.

2. Address/Data/Control Bus Buffering

The Z-80A should drive only one TTL load for each output pin and thus it becomes necessary for buffering to be used on all lines that connect to other circuitry; indeed, even a logic probe applied to an unbuffered line may cause fatal results as far as the microprocessor is concerned. Many lines drive parallel devices and buffering provides extra drive. The 74367 non-inverting tristate bus driver is capable of sinking 48 MA and can accommodate any combination of TTL, LSTTL or memory connections.

(a) Address Bus:

The 16-bit wide address bus in Figure A-5 is uni-directional and the tristate function of the 74367 is controlled by the BUSAK signal which is inverted before application to the driver's control inputs. In a non-DMA application, as in this case, the BUSAK is high and the 74367 passes all outputs from the Z-80A. If a DMA request was to be acknowledged by the Z-80A then BUSAK would go low, the 74367's placing their outputs in a high impedance mode allowing the address bus to be used by another processor for example.

(b) Data Bus:

The reason for buffering the 8-bit wide data bus is the same as for the

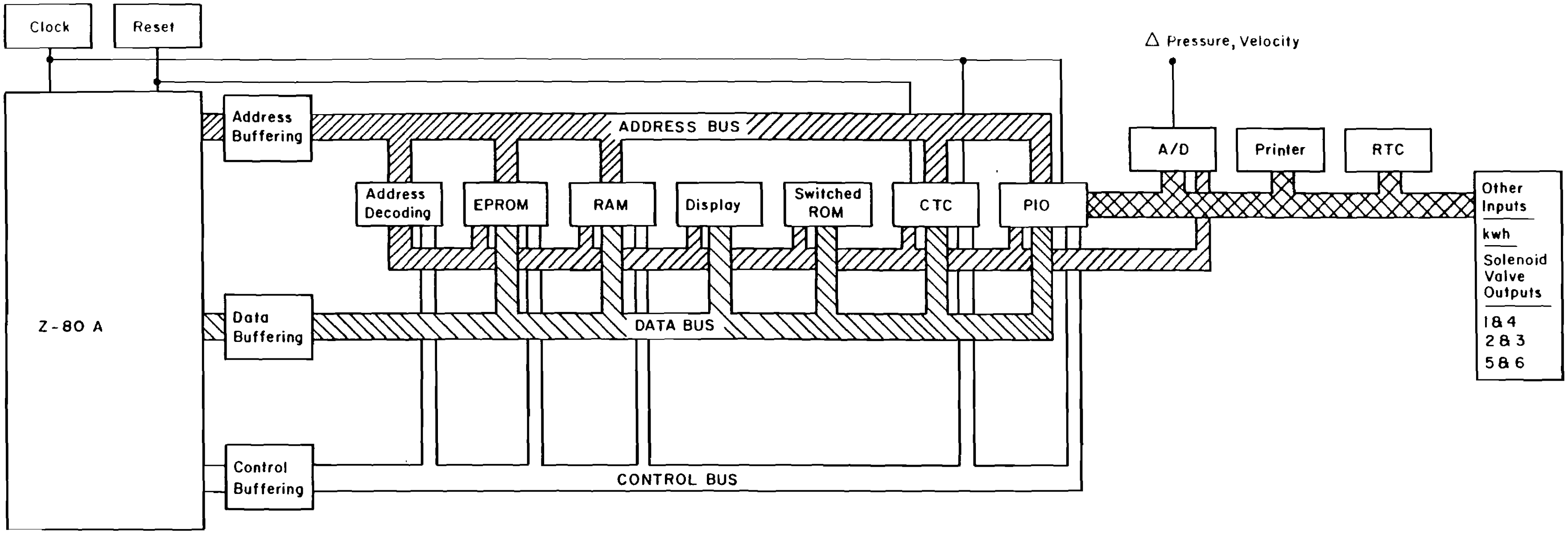


Figure A-2. Overall computing system diagram.

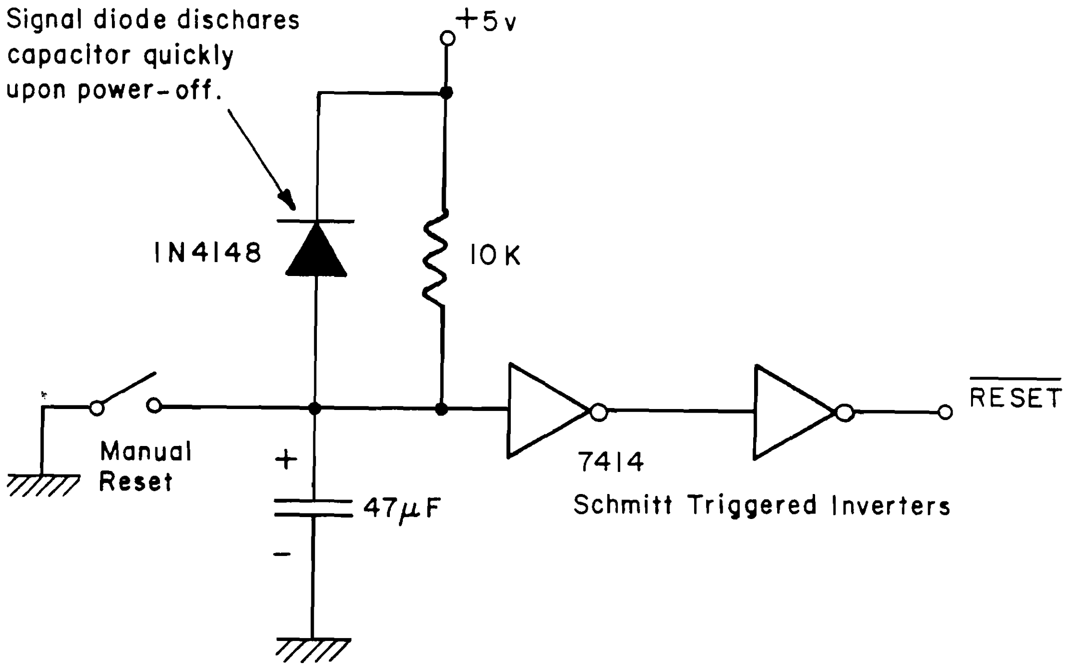


Figure A-3. Reset circuit diagram.

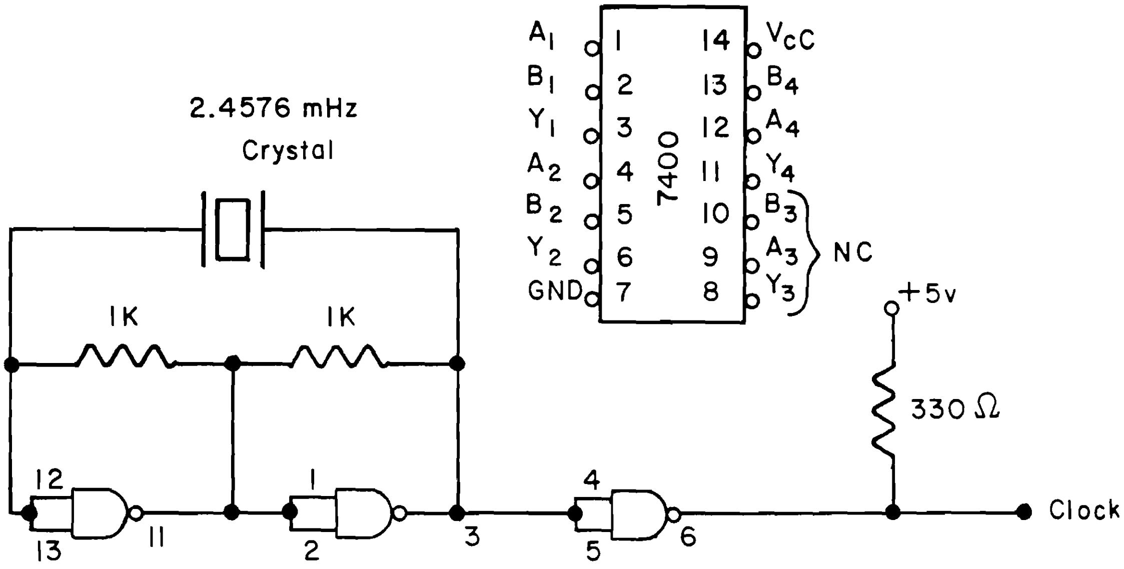
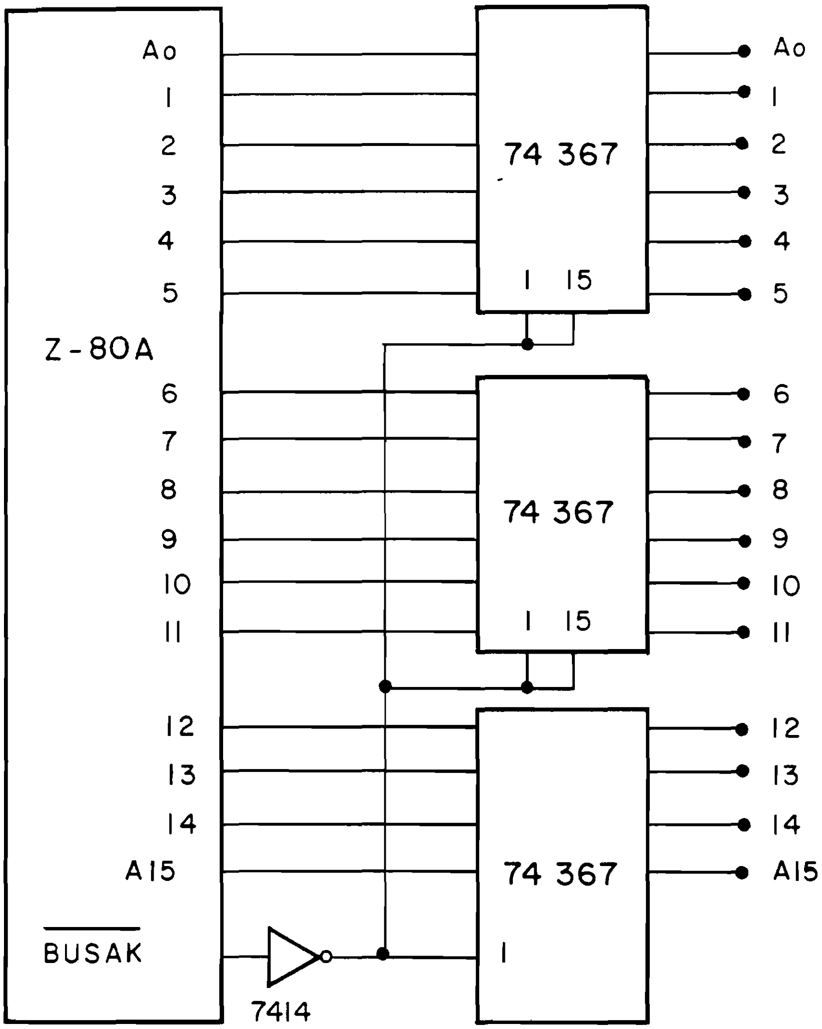
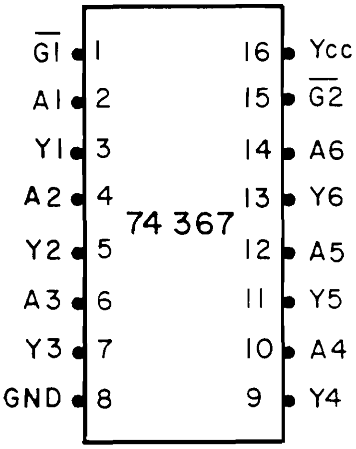


Figure A-4. Clock circuit.





INPUTS		OUTPUT
$\overline{G}$	A	Y
H	X	Z
L	H	H
L	L	L

$\overline{G1}$ controls Y1 - Y4

$\overline{G2}$ controls Y5, Y6

Figure A-5. Address bus.

address bus, but in this case we wish to make the data bus bidirectional in that data flow is channeled from associated circuits to the microprocessor and vice-versa.

By using the 74367's in opposite pairs we can accomplish the bidirectionality along with the $\overline{RD}$ read line from the processor. Recall that the tristate nature of the bus drivers enables us to effectively turn the outputs from a normal passing mode to a high impedance mode and the RD line can control this function as diagrammed in Figure A-6.

Note that in a write operation, $\overline{RD}$ is high which places the control inputs on the top two devices in a low state, allowing the data on the Z-80A data pins to be passed out onto the data bus. The lower two devices (inputs/outputs configured opposite to the other 74367's) have a high logic state present on their control pins which places their outputs in the high impedance state. The read operation is facilitated with the processor putting its $\overline{RD}$ line low and the top two 74367's go into the high impedance state, the lower two passing data from the data bus to the processor.

(c) Control Bus:

The control signals co-ordinate peripherals and channel data and addresses at the proper times, both into and out of the Z-80A. The control bus is buffered using 7414 HEX Schmitt triggers and buffering is supplied for the following signals:

$\overline{BUSAK}$, $\overline{RD}$, $\overline{WR}$, $\overline{MI}$, $\overline{IORQ}$, $\overline{MEMRQ}$

Unused input signals to the Z-80A are tied high. These include: $\overline{WAIT}$, $\overline{INT}$, $\overline{NMI}$, $\overline{BUSRQ}$. Interrupts are not supported in this system, and the $\overline{HALT}$ and $\overline{RFSH}$ lines are not used. Thus, the Z-80A is configured such that it is embedded one level using buffering on the address, data, and control busses as in Figure A-7.

3. Input/Output, Memory Address Decoding

By means of the circuit of Figure A-8 the Z-80A can directly address 65,536 (64K) individual bytes (8-bits) of program memory and 256 individual input and output ports. In this system there are available 2048 bytes of EPROM and 1024 bytes of RAM, as well as areas used in a memory mapped configuration. The CTC's and PIO's are used in an I/O environment. Both memory and I/O device addresses need to be decoded to ensure uniqueness in device selection when the address bus has placed on it a valid address by the processor.

74LS138 decoder/multiplexers are used in the 3-to-8 line decoder mode.

The 7-segment LED's and switched ROMs are decoded on 256 byte boundaries. One of the memory mapped signals is used to strobe the A/D's as shown on the diagram.

4. CTC Counter/Timer Circuits

There are two CTC's available one being used as an event timer for the revolution of the kwh meter disk. Eight revolutions of the meter disk are counted by external hardware and the state of a PIO input is flipped each time eight are counted; the time between successive high states gives the elapsed time for eight revolutions which is divided down in the program so that an average value of the power usage can be calculated. Three channels of the available four on the CTC are used to accomplished this event timing and are configured as shown in (Figure A-9.

5. PIO Input/Ouput Circuits

The PIO circuit is an interface device with 16 I/O pins, divided into two 8-bit I/O ports as shown in Figure A-10. Each I/O port has two associated control lines and each port may be specified separately as an input port, output port or control port.

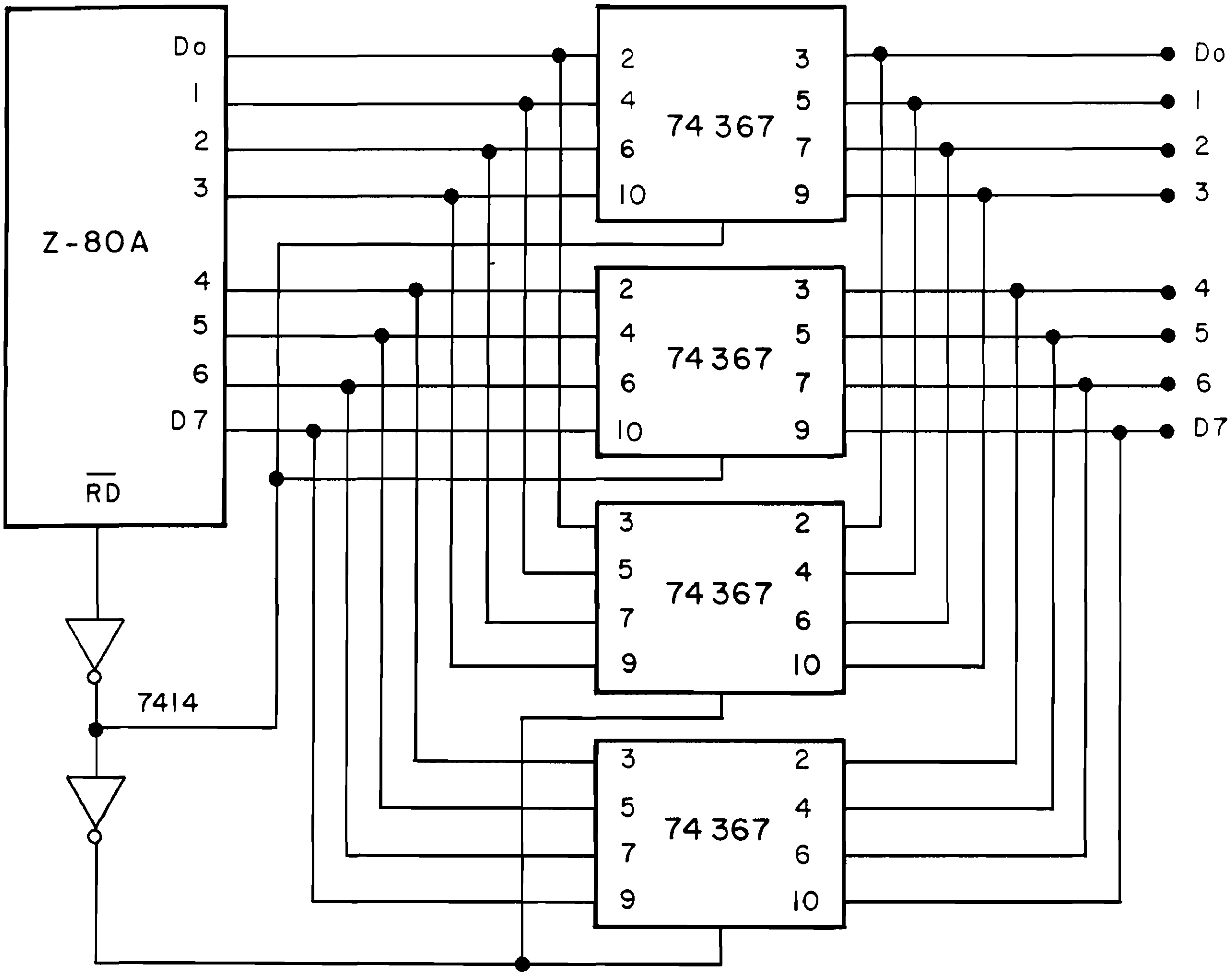


Figure A-6. Data bus.

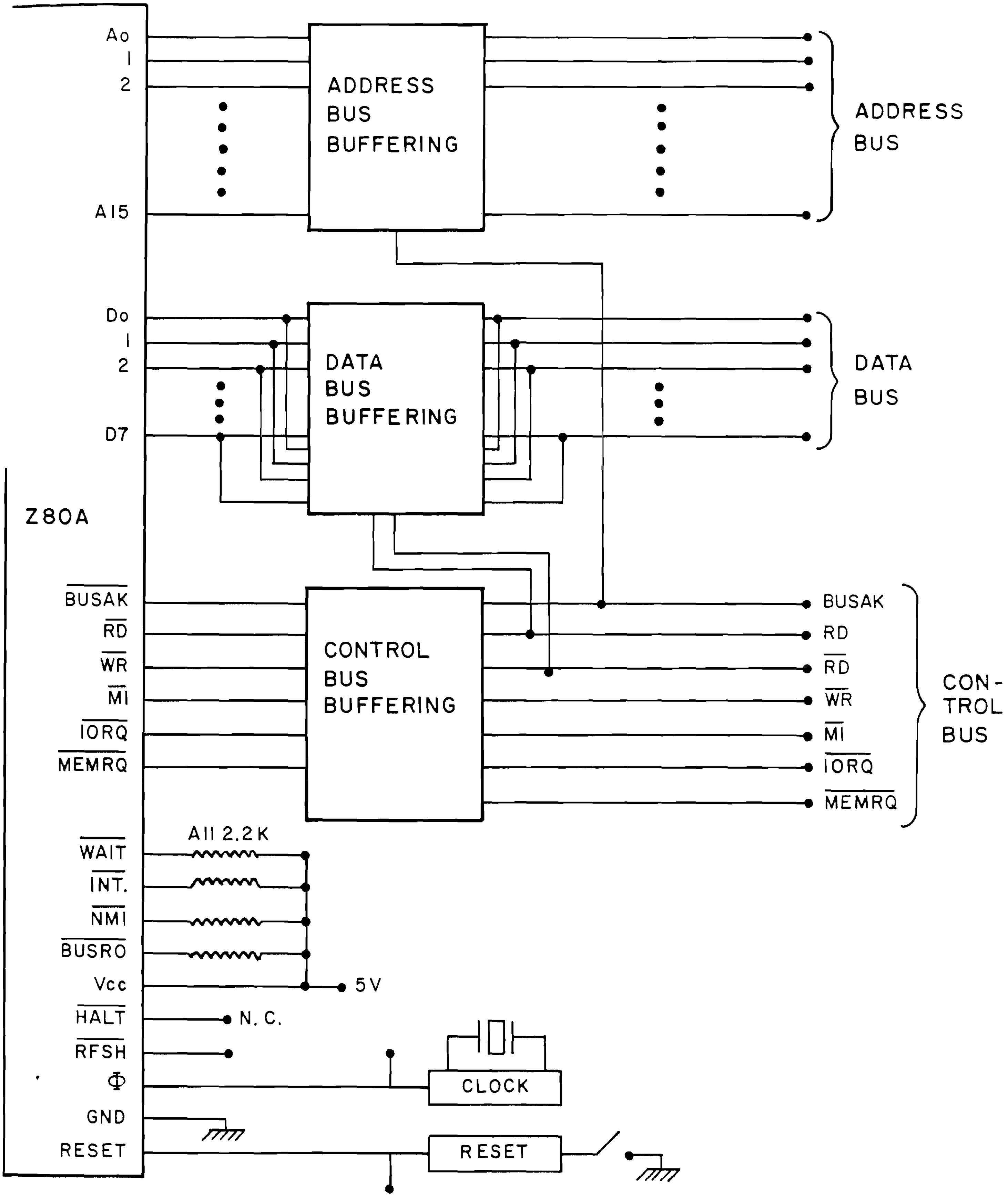


Figure A-7. Buffering of address, data, and control busses.

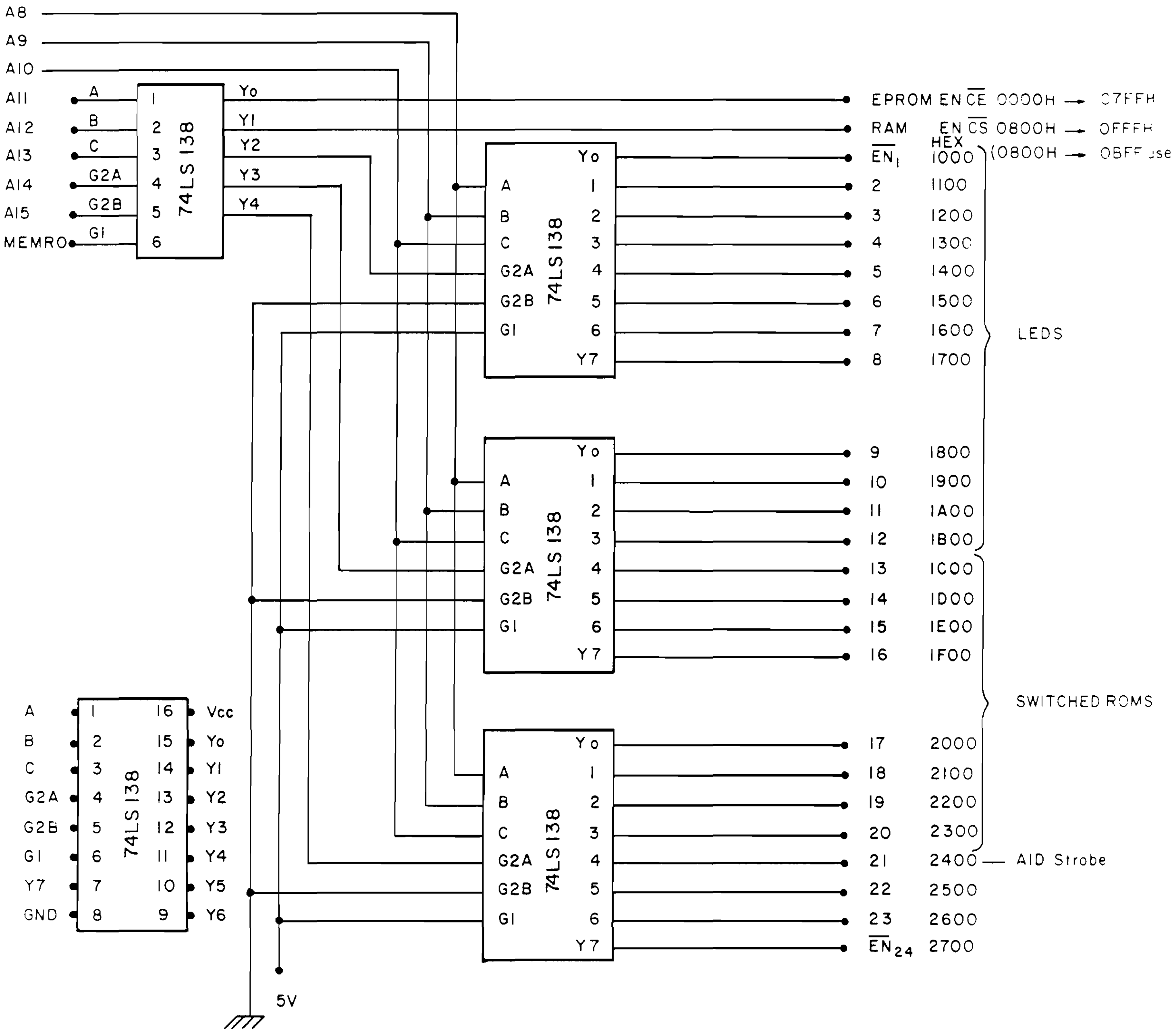


Figure A-8. Memory address decoding.

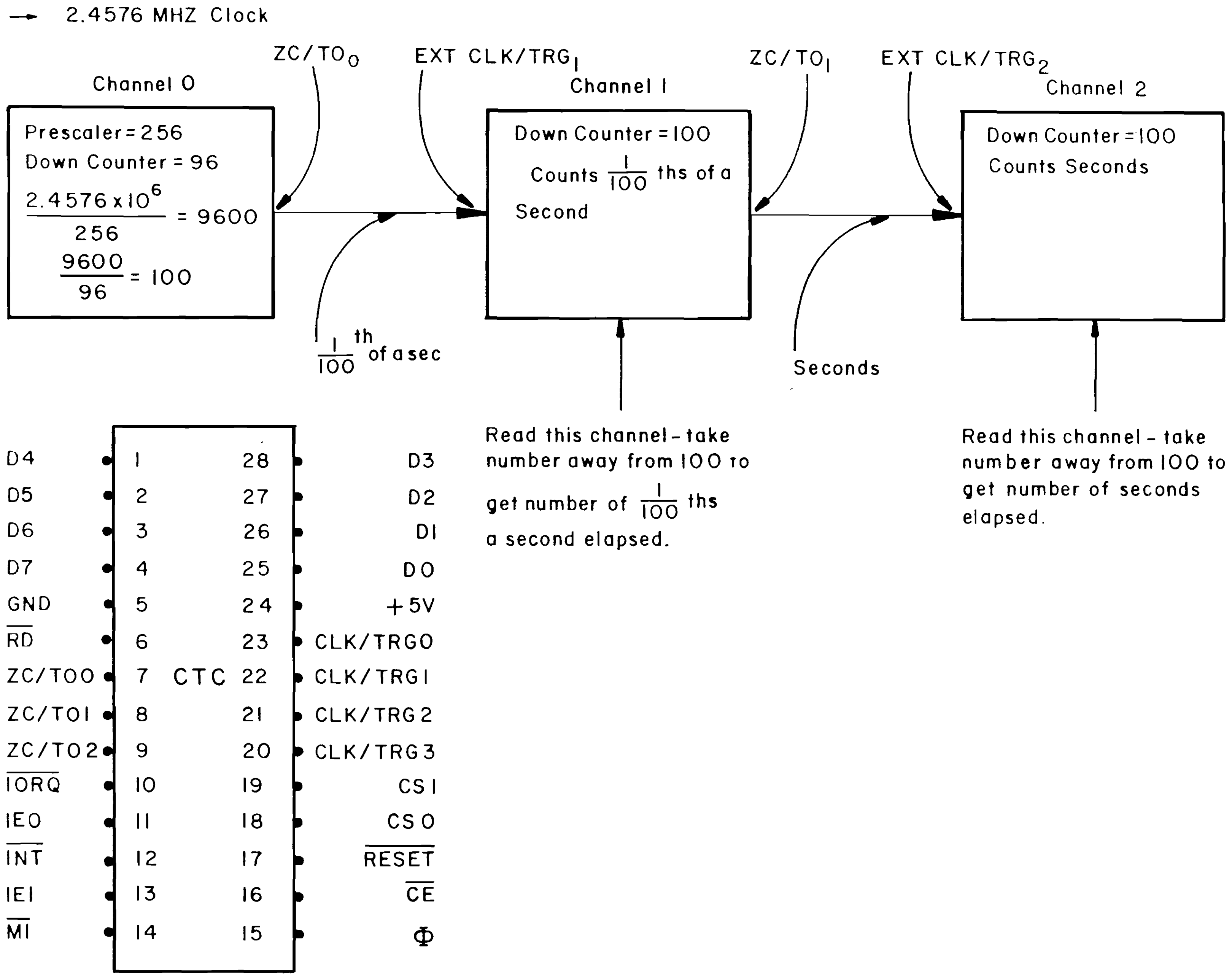


Figure A-9. Counter/timer circuits.

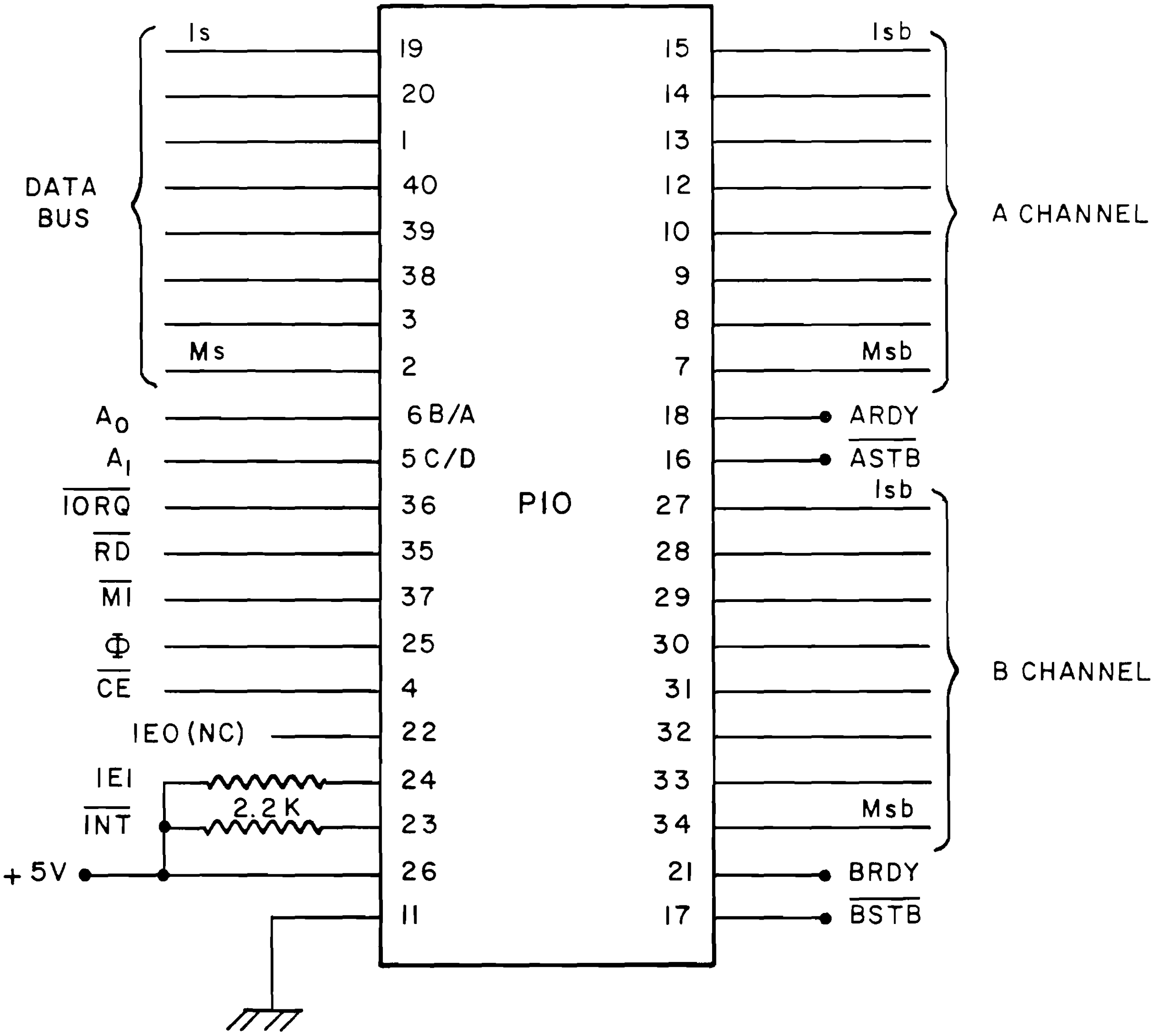


Figure A-10. Input/output circuits.

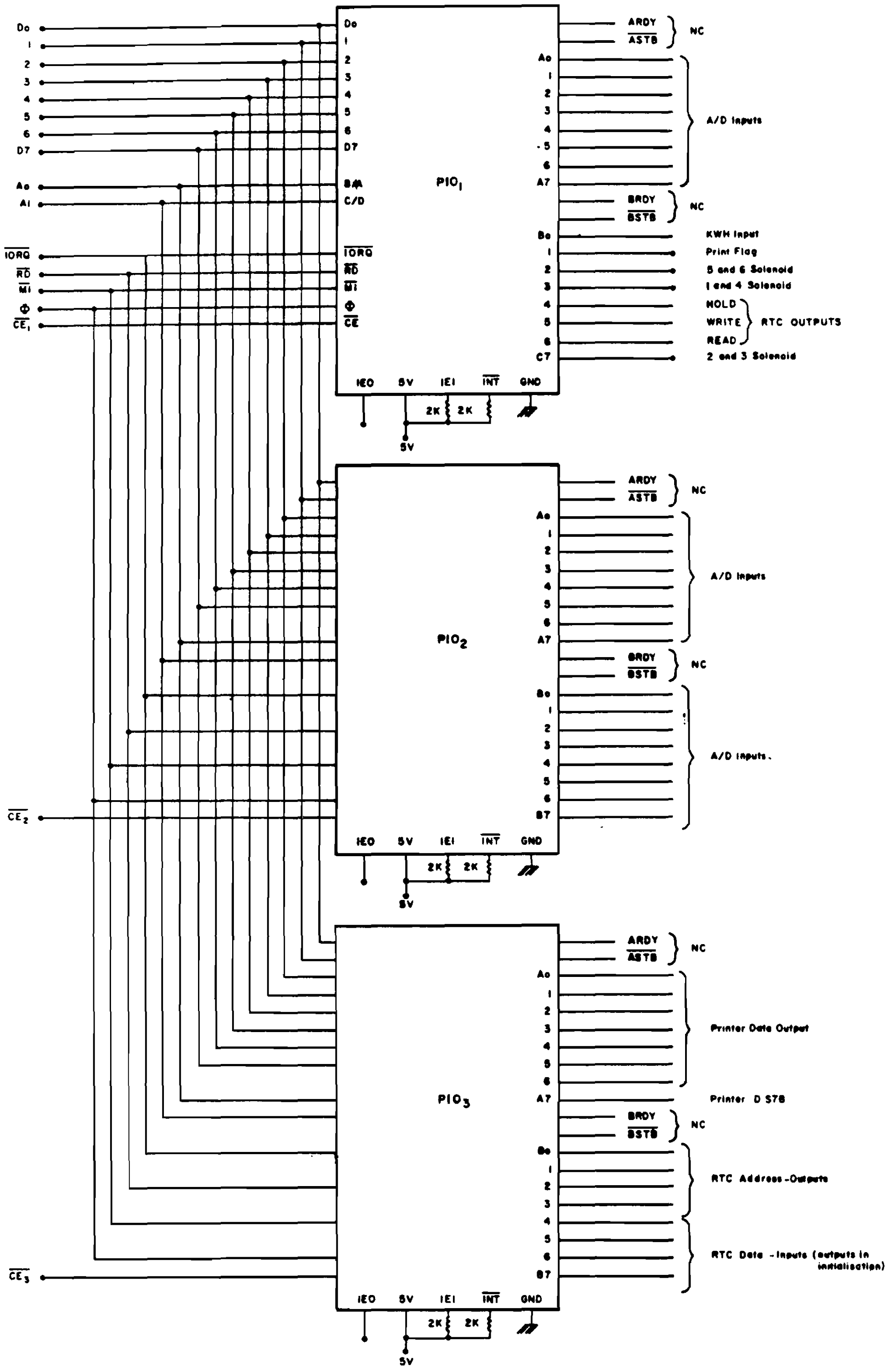


Figure A-10. Continued.

When used as a control port, each of the 8 pins may be individually assigned as an input or output. Furthermore, port "A" may be used as a bi-directional port. While not used in this implementation, the PIO is capable of providing significant interrupt handling capability making the circuit a powerful parallel interface device.

For ease of use, the PIO's in this system have been configured in the control mode (Mode 3). The control signals are not used in this mode and every port pin is defined as either input or output which is easily accomplished in PIO initialization.

6. Analog-to-Digital Conversion

Three ADC0804LCN A/D's have been provided as shown in Figure A-11, two being used in this system; one A/D is used to convert the voltage produced by the bubbler tube pressure transducer and the other converts the voltage from the accutube velocity measuring device via a pressure transducer. The A/D's are used in the free-running mode and strobed by one of the memory mapped outputs.

7. RAM/ROM-Memory Devices

As noted in Figure A-12, both volatile (RAM) and non-volatile (EPROM, ROM) memory is provided, and the program itself is contained in an EPROM capable of storing 2048 bytes. It is decoded to reside in the first 2K of memory, locations 0000HEX - 07FFHEX. The program is listed in Appendix B.

The RAM is used for stack area and temporary storage; 1K is available in hardware but memory space has been left for an extra 1K of RAM. It is mapped in the 2K following the EPROM area, 0800HEX - 0FFFH (0800HEX - 0BFFHEX in hardware).

8. Switched ROM Devices

Many of the variables contained in the efficiency equation are peculiar to the physical location of the pumping system and thus need to be altered according to the site. Adapting the EPROM to suit each location would be tedious and thus 8 x 8-bit switched ROMs in the form of 8 dual-in-line switches have been provided as in Figure A-13. Values of relevant site variables can be initially set up on the switches and the program reads these as actual memory locations as if each 8-bit variable was indeed a memory location in ROM for example. A change in site requires only a change in the switch settings, making EPROM alteration unnecessary. The switches also serve the dual purpose of setting up the RTC upon initialization of this timing device.

The switched ROMs are decoded according to the scheme discussed in the memory decoding section. The 74C240 inverting output octal buffer and line driver with tristate output devices are so designed to drive bus-oriented systems. By strobing the $\bar{G}$ inputs high, the outputs go into the high impedance state. With the DIL switch in the open position the input to the 74C240 is high and upon inversion places a low on the data bus for the bus line corresponding to the particular switch. By closing the switch, the current is drawn through the 22K resistor to ground and the 74C240 input goes low, and again, upon inversion, the data bus line receives a high.

As noted previously, the switches allow initialization data to be input to the real time clock. The RTC must be set up to the actual time of initialization so that events can be related to the real time as it progresses. By setting one bit aside as a flag bit, it is possible to write this information to the RTC via the DIL switches and then after placing the flag switch in the reset mode the normal site switch data can be set on the switches ready for standard operation (see Figures A-14 and A-15).

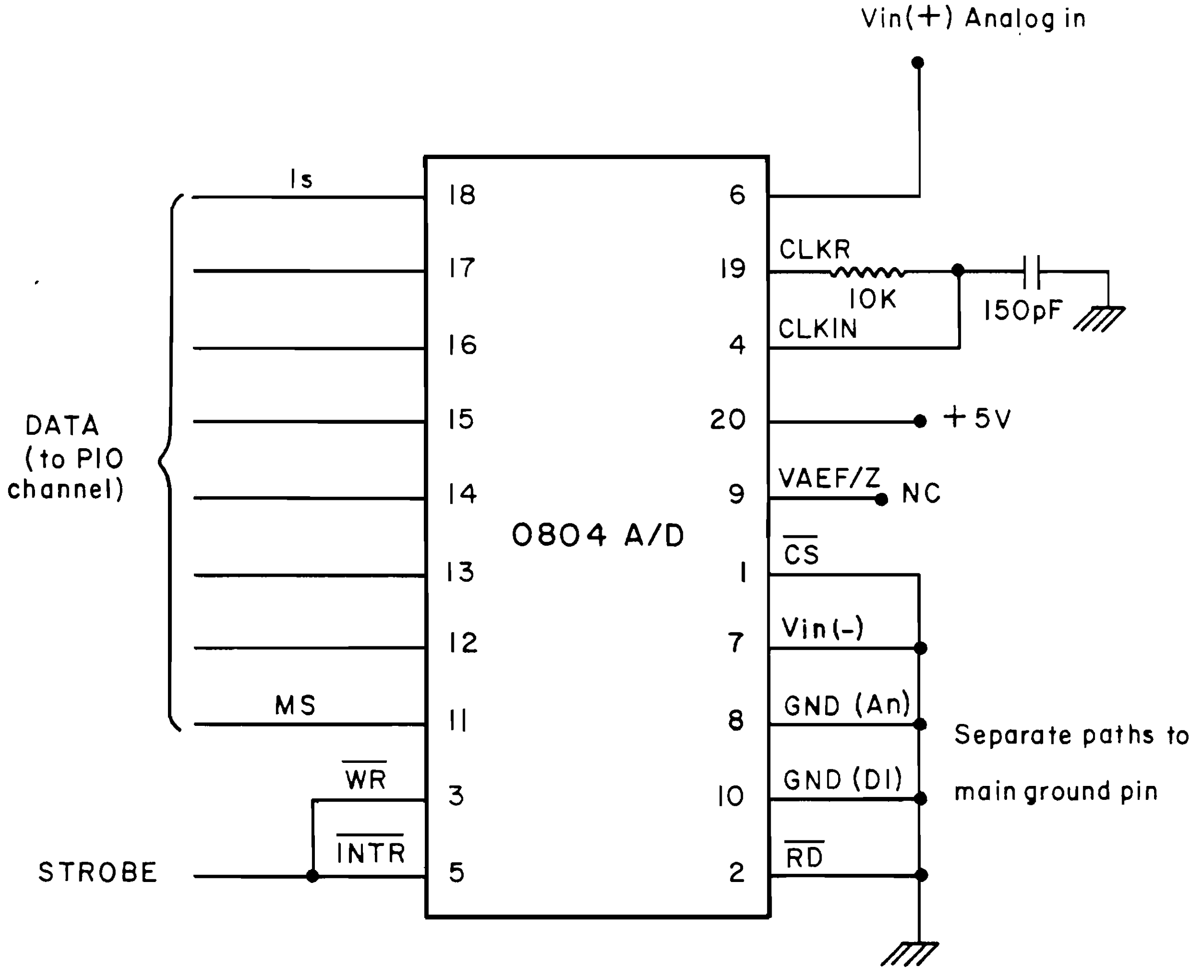


Figure 11. Analog to digital conversion circuits.

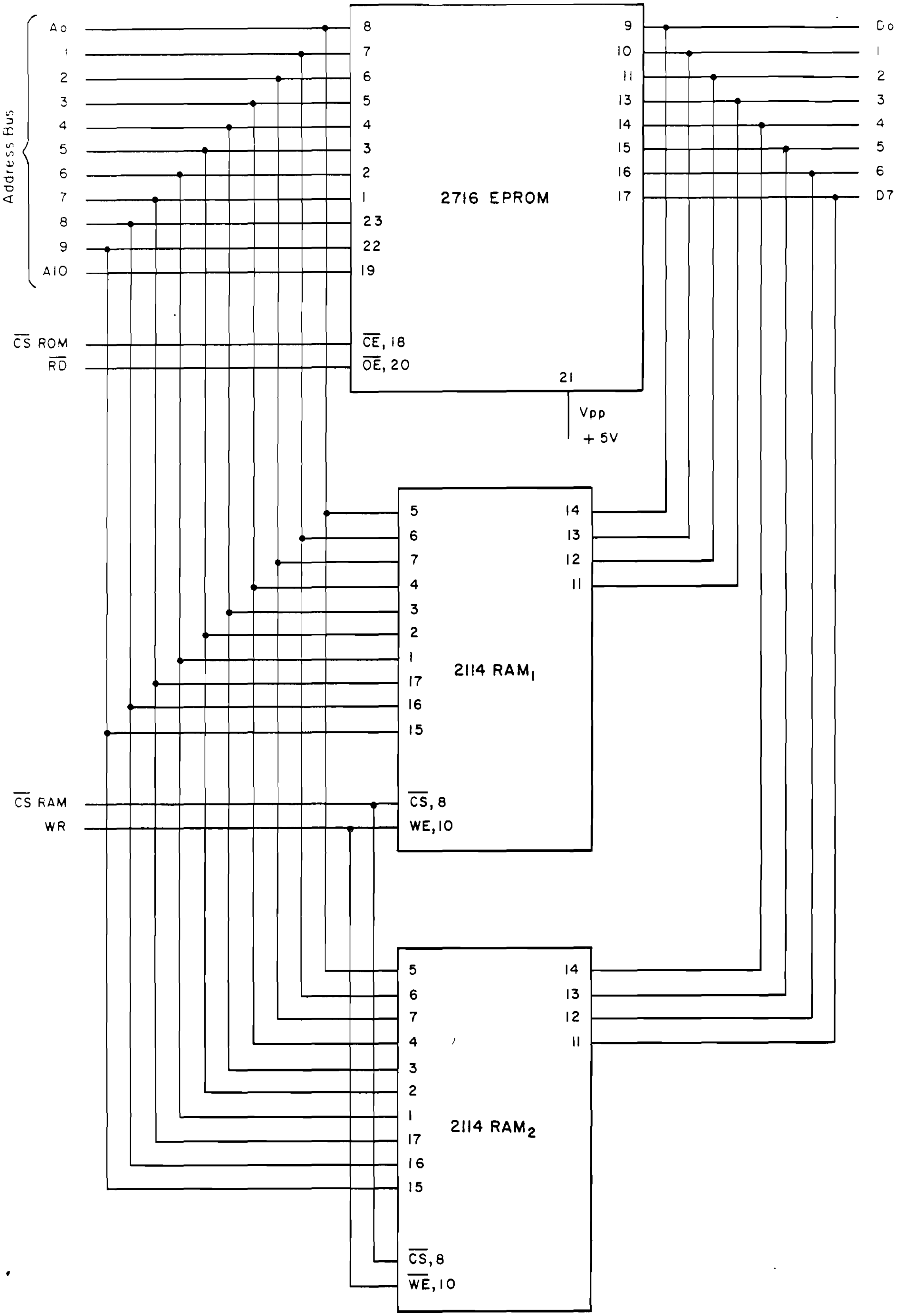


Figure A-12. RAM/ROM memory devices.

	HEX		
	0800 ↓ 0829	STACK	
KTIM	082A	Start KW time	Low
	082B		High
TEMPI	082C	KW Time Lapse	Low
	082D		High
POWIN	082E	KW-Binary	Low
	082F		High
DELTAP	0830	Pressure-Binary	Low
	0831		High
PVEL	0832	Velocity	High
	0833	MSWORD	Low
	0834	Velocity	High
	0835	LSWORD	Low
LIFTT	0836	Lift Binary	Low
	0837		High
PVELD	0838	Velocity Squared	High
	0839	MSWORD	Low
	083A	Velocity Squared	High
	083B	LSWORD	LOW
RAMPT	083C	Efficiency	High
	083D	BCD	Mid
	083E		Low
	083F	Power in	High
	0840	BCD	Mid
	0841		Low

	HEX		
	0842	Lift	High
	0843	BCD	Mid
	0844		Low
	0845	Flow	High
	0846	BCD	Mid
	0847		Low
DEN	0848	Divide Routine	Low
	0849	Temporary Storage	High
NVM	084A	Divide Routine	Low
	084B	Temporary Storage	High
FLOWW	084C	Flow Binary	Low
	084D		High
VELZER	084E	Velocity Zero Reading	
PRIFL6	084F	Print Flag	
	0850 ↓ 085F	NOT USED	
	0860 ↓ 08C1	RAM PRINT BLOCK	

Figure A-12. Continued.

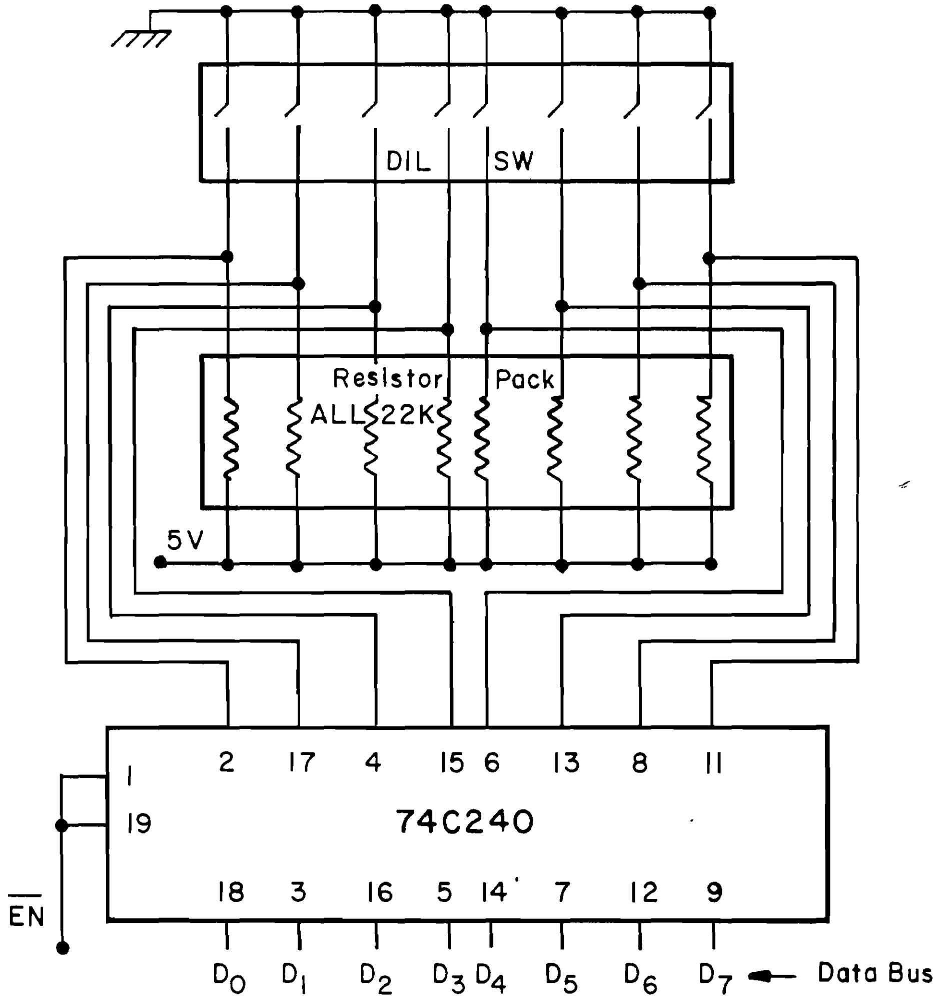
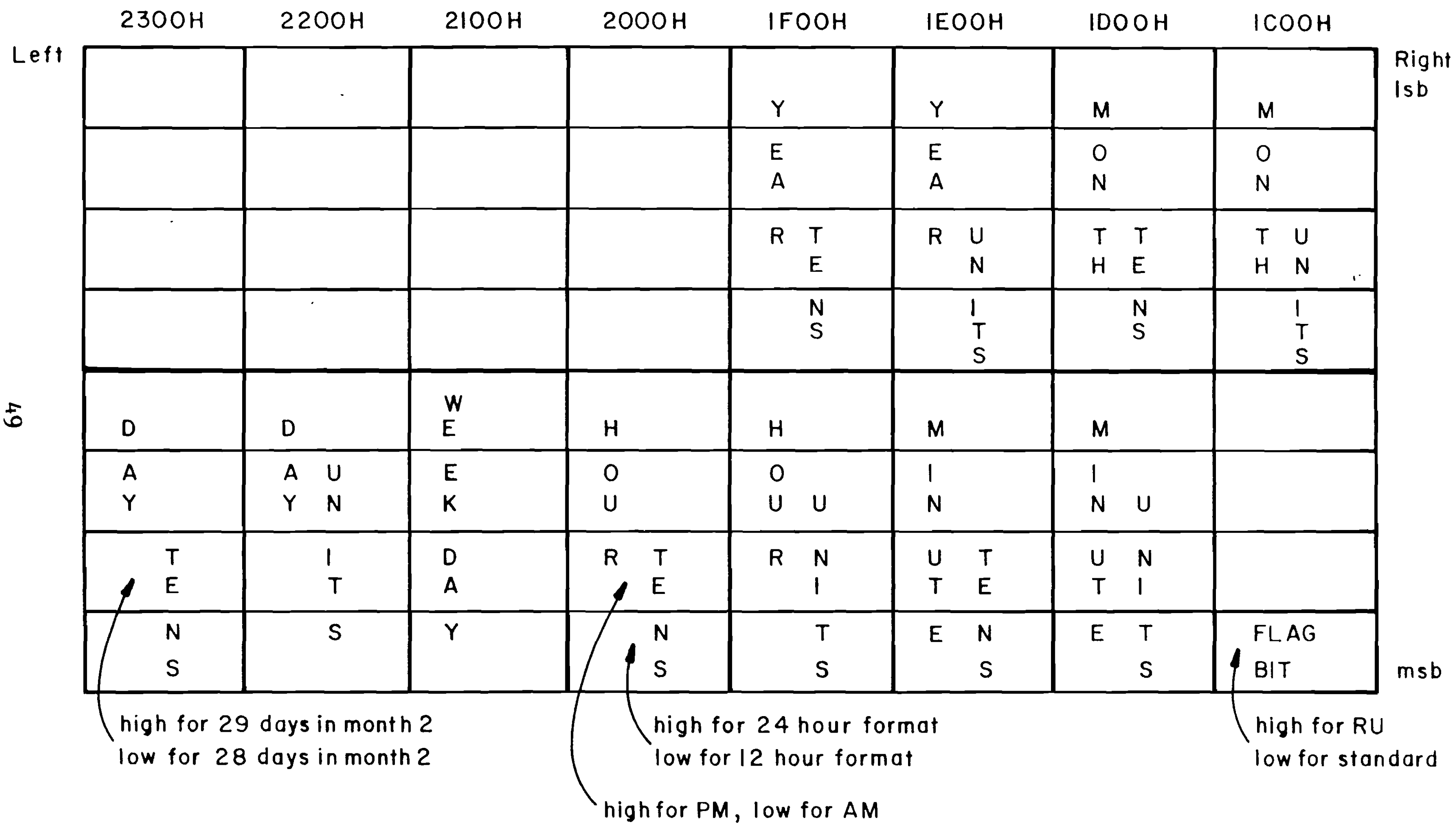


Figure A-13. Switched ROM devices.



high for 29 days in month 2
low for 28 days in month 2

high for PM, low for AM

high for 24 hour format
low for 12 hour format

high for RU
low for standard

Figure A-14. Real time clock variable map.

	2300H	2200H	2100H	2000H	1F00H	1E00H	1D00H	1C00H	
Left	0	0	8	M E 0	A 0	8	F 0	8	Right lsb
	1	1	9	T E 1	R E 1	9	L O 1	9	
	P R 2	D I 2	10	R 2	A 2	10	W 2	10	
	E F S A 3	S T 3	11	F 3	F O A 3	0	S 3	11	
	S C U T 4	A N 4	12	A C 4	F C T 4	T 1	C A F 4	S I 0	
	R O E R 5	C E 5	8	T O 5	O P R 5	I M 2	L A I C 5	T E 1	
	6	(H) 6	9	R 6	I P 6	E 3	N T G O 6	No. 2	
	7	7	10	K_H 7	E 7	4	R 7	FLAG BIT	msb

$\frac{1}{10}$ th's of feet

$\frac{1}{10}$ ths of meter factor units

$\frac{1}{1000}$ ths of square feet

hours 24-hr format

$\frac{1}{100}$ ths of scale factor units

Figure A-15. Normal location variable map.

9. 7-Segment Display

As noted in the decoding section. The LED display is also memory mapped.

The 4511 BCD-to-7-segment latch/decoder/driver is the integrated circuit used to drive the 7-segment displays (HP-5082-7740) directly. The 4 low order bits of the data bus are used to provide data to the 4511's which are enabled under program control (see Figure A-16).

10. RTC-Real Time Clock

The real time clock is available to give a record of the events with respect to time; the clock can give readings resolved to one second. The format is as follows:

YY	MM	DD
YEAR	MONTH	DAY OF MONTH

W	HH	MM	SS
WEEK-DAY	HOUR	MINUTE	SECOND

1 = January etc, 0 = Sunday,
1 = Monday etc.

The set-up is accomplished as explained earlier in the switched ROM section; the PIO interface enables data transfer to and from the RTC. Pull-up resistors of 10K ohms are connected to the data, address and control pins of the clock chip.

11. Printer

The ALPHACOM Sprinter 20 (20 columns wide) is used to provide a more permanent copy of the readings and a full report can be generated on a once per day basis or on demand. The lines from the accutube flow meter are bled prior to the printed output and the accutube pressure transducer is zeroed so that errors are kept to a minimum. Once an error voltage on the accutube pressure transducer is recorded in memory it is used to adjust the subsequent velocity readings until another print/zero transducer reading is requested. A switch on the processor unit is used to select once/day readings or a demand reading. If the switch is left in the continuous setting the printout sequence will occur repetitively, whereas with the once/day setting this task is performed at a particular hour each day. The program is written so that a print/zero sequence is only performed if the pump has been operating at least 5 minutes so that any transients have had some time to settle down.

The print-out sequence is made up of three sets of bleed, zero, and normal operations (i.e., accutube pressure is across velocity pressure transducer) with velocity data being taken at the end of the zero and normal operating times. A print-out is generated for each of the three sets, the complete operation taking approximately 20 minutes. The system is left in the normal operating mode with the data being displayed on the LED's but not printed. The most recent zero reading is used in subsequent calculations.

The printer receives data and control signals via a PIO interface device. The report includes the following:

```
                        Example:

SITE#X XX XX XXX XX     SITE#1 MO 17 JAN 83
TIME XX:XX:XX           TIME 13:39:36
EFFICIENCY (%) XX.X     EFFICIENCY (%) 51.5
POWER IN (KW) XX.X      POWER IN (KW) 69.6
LIFT (FEET)  XXX        LIFT (FEET)  285
FLOW (CFS)      X.XX    FLOW (CFS)      1.49
```

An example depicting initialization is necessary. The RTC is first set up for an appropriate time; this time is chosen so that upon momentary depression of the

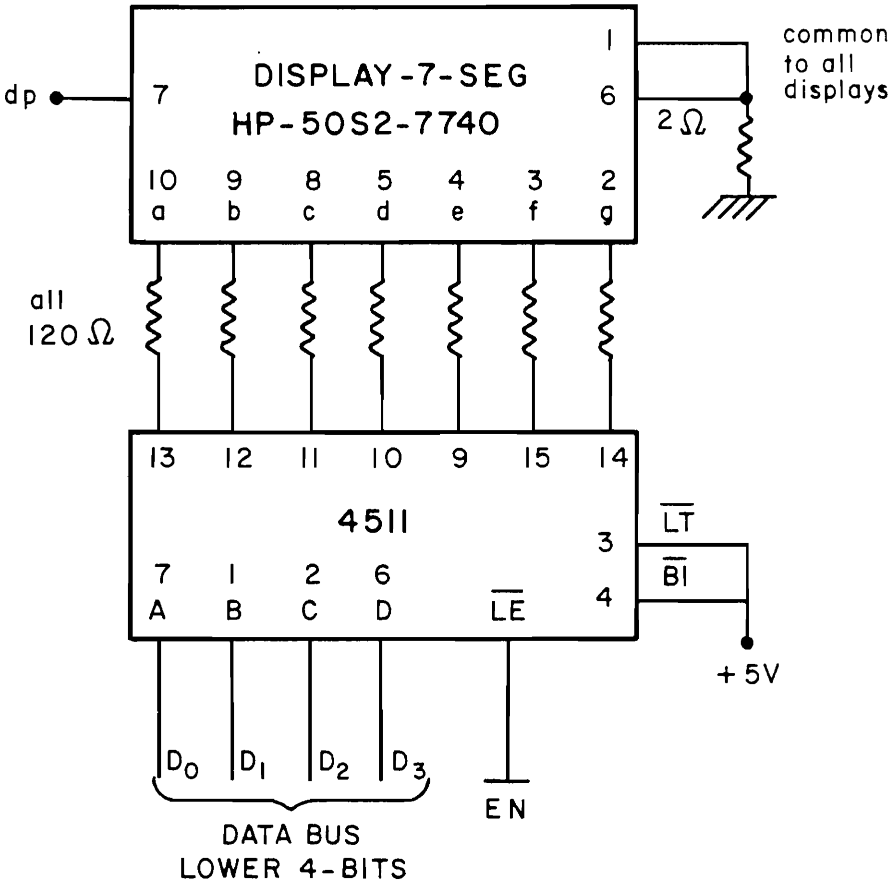


Figure A-16. Display circuit.

$\overline{\text{RESET}}$ button the time as set up on the DIL switches will be loaded into the RTC at that very instant. An example time is: Monday the 17th of January, 1983 and it's 39 minutes past 1 in the afternoon (i.e., 1339 hours).

YEARS TENS = 8 = 1000 LEAST
YEARS UNITS = 3 = 0011 SIGNIFICANT
MONTHS TENS = 0 = 0000 AT
MONTHS UNITS = 1 = 0001 RIGHT
DAYS TENS = 1 = 0001*
DAYS UNITS = 7 = 0111
WEEKDAY = 1 = 0001
HOURS TENS = 1 = 1101*
HOURS UNITS = 3 = 0011
MINUTES TENS = 3 = 0011
MINUTES UNITS = 9 = 1001
FLAG BIT SET = 1XXX X=DON'T CARES

*The third L.S.B. set on days tens would signify 29 days in February while a reset bit means 28 days. Thus a leap year would have days tens as 0101. Likewise with the hours tens; the third L.S.B. set means that we are using a 24 hour format, and reset 12 hour format. A set fourth bit in hours tens signifies p.m. and reset a.m.

Using the same time group map as was given in the switched ROM section and repeated again below we can set up the initialization time for the RTC as in Figure A-18.

Once the $\overline{\text{RESET}}$ button has been momentarily depressed. The real time has been loaded in for RTC initialization, and it is now possible to set up the switches to hold the site variables. We can choose some appropriate site variables:

LIFT PRESSURE TRANSDUCER FULL SCALE (PSI)
= 100 = 01100100
DISTANCE H (IN TENTHS OF FEET)
= 2325 = 100100010101
KH KWH METER FACTOR (IN TENTHS)
= 1152 = 10010000000
AREA OF PIPE (IN THOUSANDTHS OF SQ. FEET)
= 369 = 00101110001
TIME OF DAY TO PRINT/ZERO (24 HR. FORMAT)
= 13 = 01101
VELOCITY PRESS.TRANS.F.S.(HUNDREDTHS OF INCH)
= 2000 = 011111010000
SITE IDENTIFICATION NUMBER
= 1 = 001
FLAG BIT MUST BE RESET
= 0 = 0

Load onto switches using Figure A-19.

The above memory mapped locations will be treated as site variables because the flag bit (bottom right hand corner) is not set. It is a good idea to reset this bit a few seconds after depressing the $\overline{\text{RESET}}$ button momentarily when setting up the RTC initialization data, and then set up the switches for the site variables. This ensures that the switches will not be read as RTC data when the program flow loops back to test this bit. Once the site variables have been loaded with the flag bit previously reset then the complete initialization task is finished.

12. Compressor Unit

The air compressor unit is powered by a separate power supply (Figure A-20) and is controlled by a pressure switch mounted on the air tank. As long as the power is on, this system will maintain the pressure set by the pressure switch (approximately 45 psi maximum). This air pressure is used to feed the bubbler tank to provide data on the effective lift over which the pump operates.

13. Data Gathering and Control Circuits

The data gathering and control electronics consist of control circuits to establish the various measurement conditions and transducers to convert these conditions to electronic signals. The circuitry required to accomplish these measurements is shown in Figure A-21. The solenoid valves are connected as shown in Figure A-22.

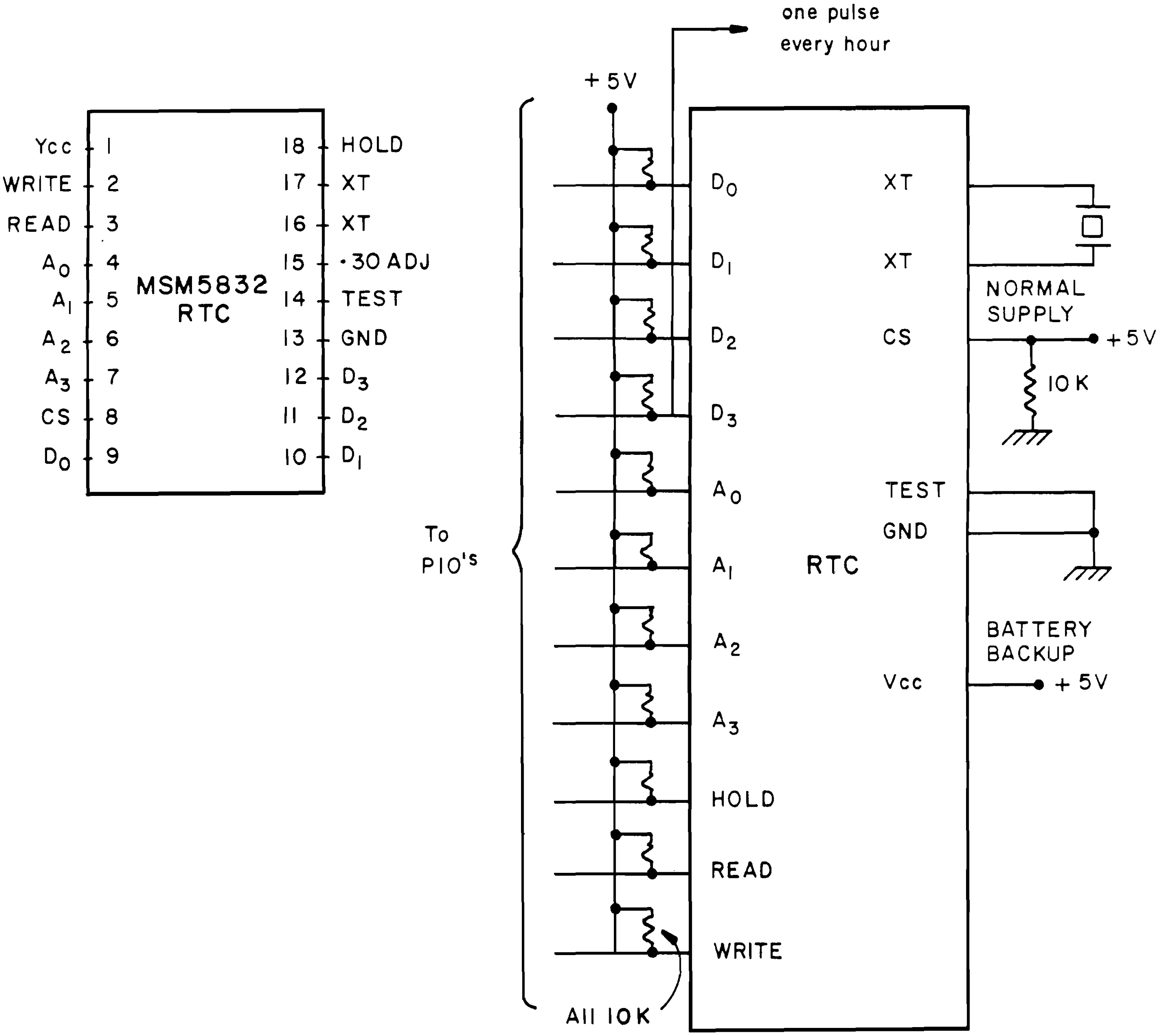
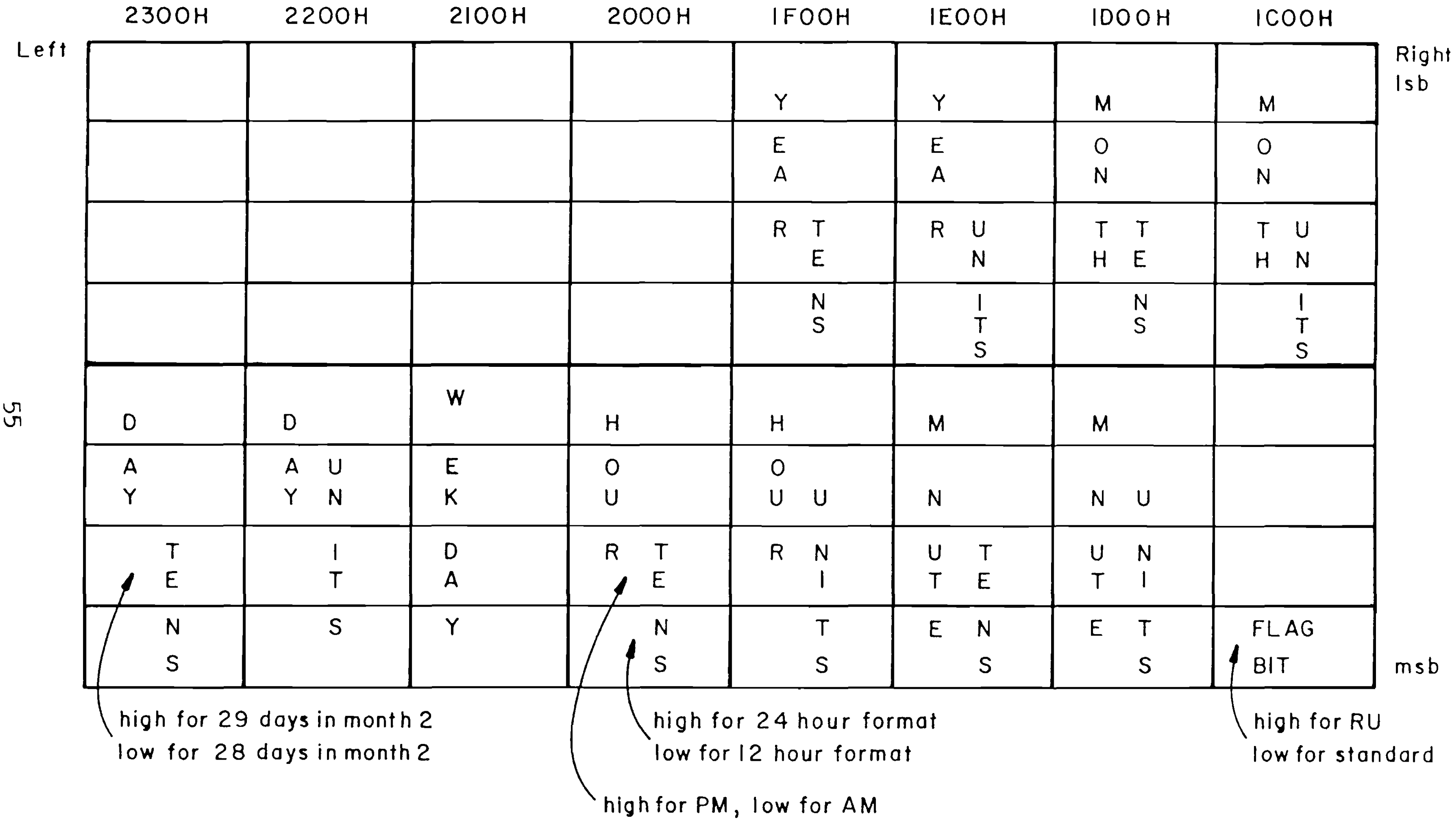


Figure A-17. Real time clock circuit.



high for 29 days in month 2
low for 28 days in month 2

high for 24 hour format
low for 12 hour format

high for PM, low for AM

high for RU
low for standard

Figure A-18a. RTC map for switched ROMS.

X	X	X	X	0	1	0	1	TOP OF BOARD RIGHT HAND SIDE LEAST SIG. BIT
X	X	X	X	0	1	0	0	
X	X	X	X	0	0	0	0	
X	X	X	X	1	0	0	0	
1	1	1	1	1	1	1	X	
0	1	0	0	1	1	0	X	
0	1	0	1	0	0	0	X	
0	0	0	1	0	0	1	1	MOST SIG. BIT

Figure A-18b. Example switch settings for RTC.

0	0	0	0	1	1	0	1	TOP OF BOARD RIGHT HAND SIDE LEAST SIG. BIT
0	1	0	0	0	0	0	1	
1	1	0	0	0	0	0	1	
0	0	1	0	0	1	0	0	
0	0	0	0	1	0	1	1	
1	1	0	0	1	1	0	0	
1	1	0	0	1	1	1	0	
0	1	1	1	0	0	1	0	MOST SIG. BIT

Figure A-19. Example switch settings for site variables in the switched ROMS.

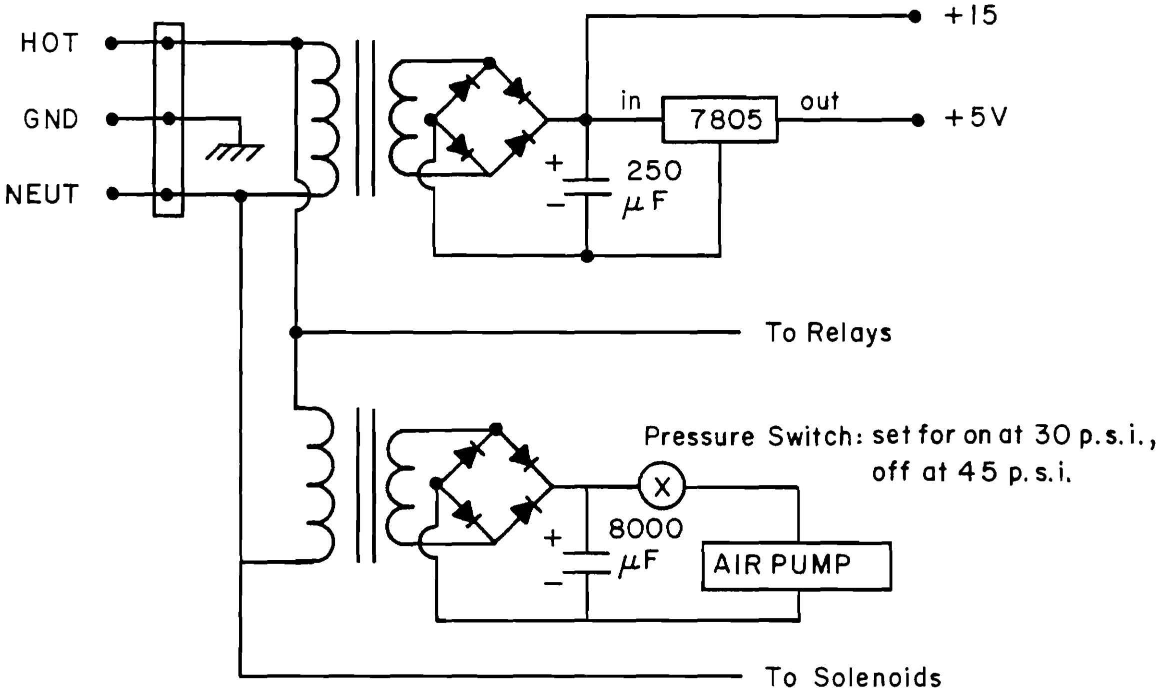
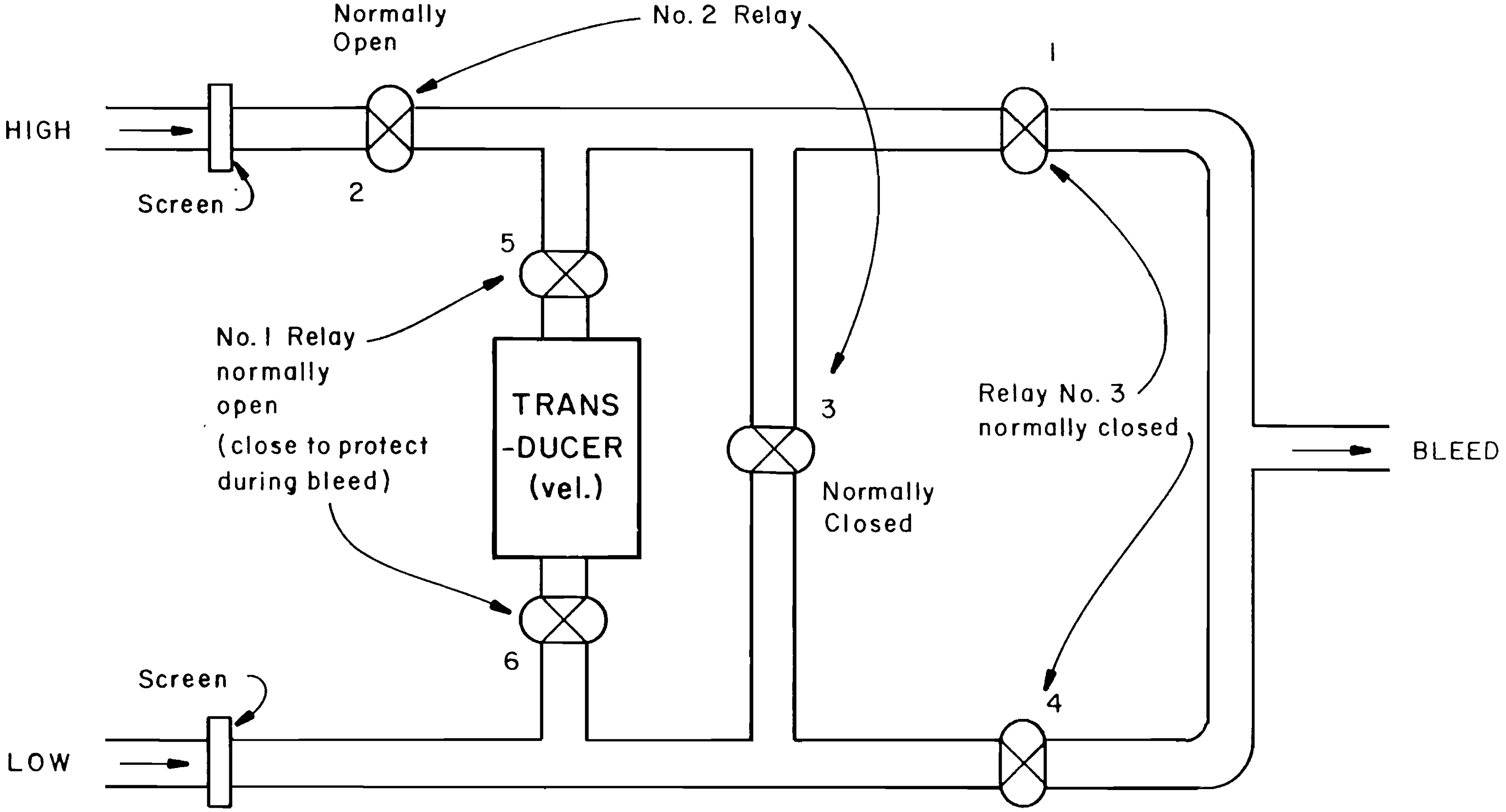


Figure A-20. Power supply for compressor unit.



Relay No. 1 (Solenoid Valves 5 and 6) - Protection
Relay No. 2 (Solenoid Valves 2 and 3) - Zero Reading
Relay No. 3 (Solenoid Valves 1 and 4) - Bleed

Figure A-21. Diagram of solenoid valves and relay controls.

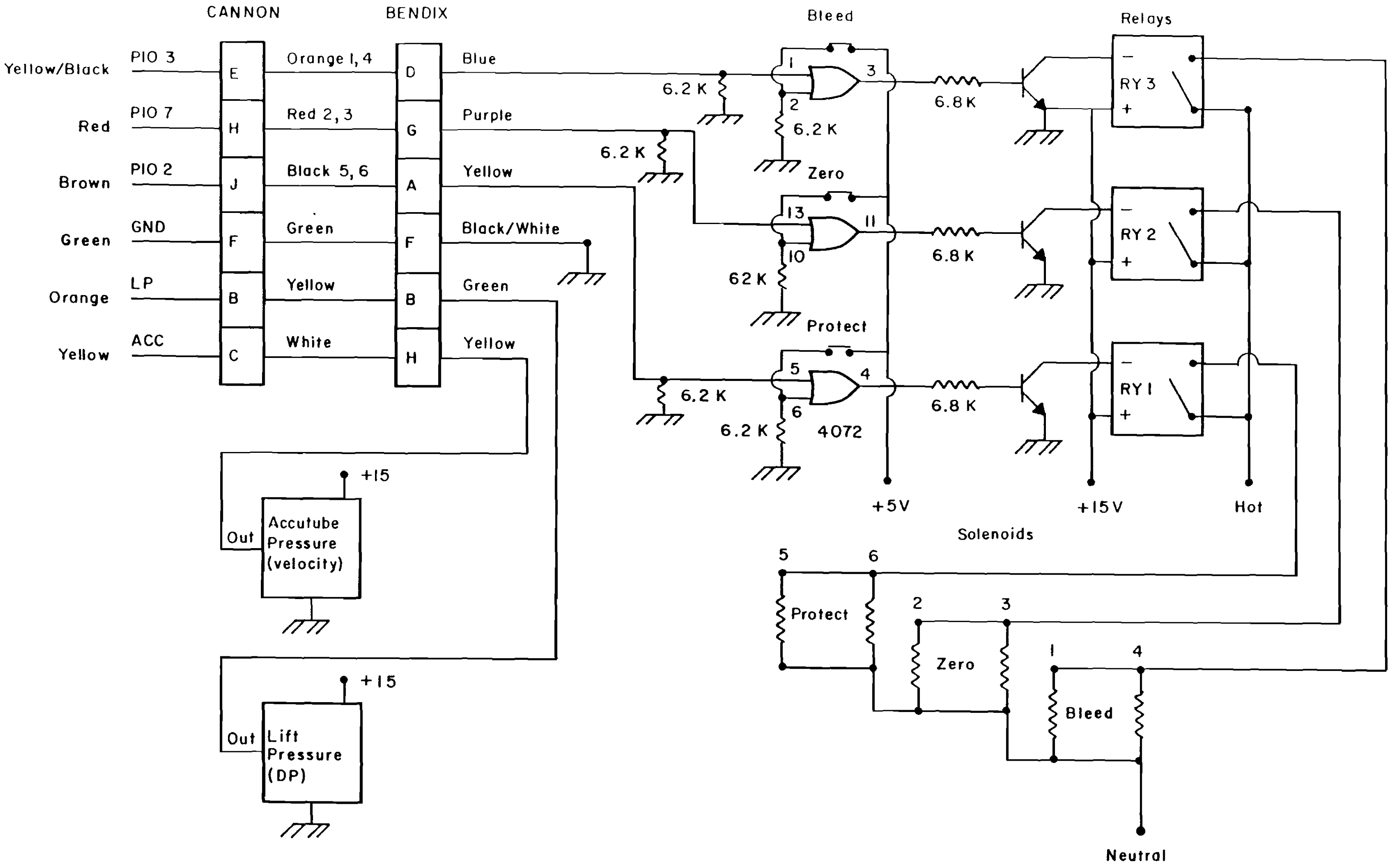


Figure A-22. Compressor unit connector, solenoid, relay, and transducer connections.

The solenoids operate in pairs with 1 and 4, 2 and 3, 5 and 6 tied together. As noted in Figure A-21, solenoid valves 2, 5, and 6 are normally open and 1, 3, and 4 are normally closed. The function of each pair of valves is described below:

Valve Numbers	Function
1 and 4	Air bleed to purge the system
2 and 3	Establish conditions to obtain a zero reading
5 and 6	Protection of the sensitive pressure transducer

The operation of these is normally controlled by the computer program. The manual controls for initial setup should be used with caution. The protection solenoids (5 and 6) should always be actuated (by pressing the white button) before actuating the bleed valves (pressing the small red button). The zero solenoids (black button) would be actuated whenever a zero reading is desired. The program controls the valves as shown in the timing diagram (Figure A-23).

A readout cycle, initiated by the computer program, begins by closing the protection solenoid valves. Two seconds later the air bleed valves are opened and remain open for approximately 17 seconds. At the end of the air bleed period solenoid valves 1, 4, 5, and 6 are all de-energized and valves 2 and 3 are energized. Solenoid valve 3, when energized, provides a shunt path around the transducer so that no differential pressure can exist across the transducer. Solenoid valve 2, when energized, closes off any flow so that the zero reading is not affected by any dynamic water movements. This zero reading is taken just prior to the data reading so that any drifts due to temperature or supply voltage can be subtracted out of the data reading.

The control signals from the computer are passed through "or" gates which permit manual operation of each pair of solenoid valves as shown in Figure A-22.

Because of the large range of the "line pressure" transducer and the resulting low volts/psi output, it is not necessary to zero this unit.

The outputs from the two transducers are fed back to the computer unit where they are smoothed by the circuit shown in Figure A-24 and then used in the final efficiency calculation.

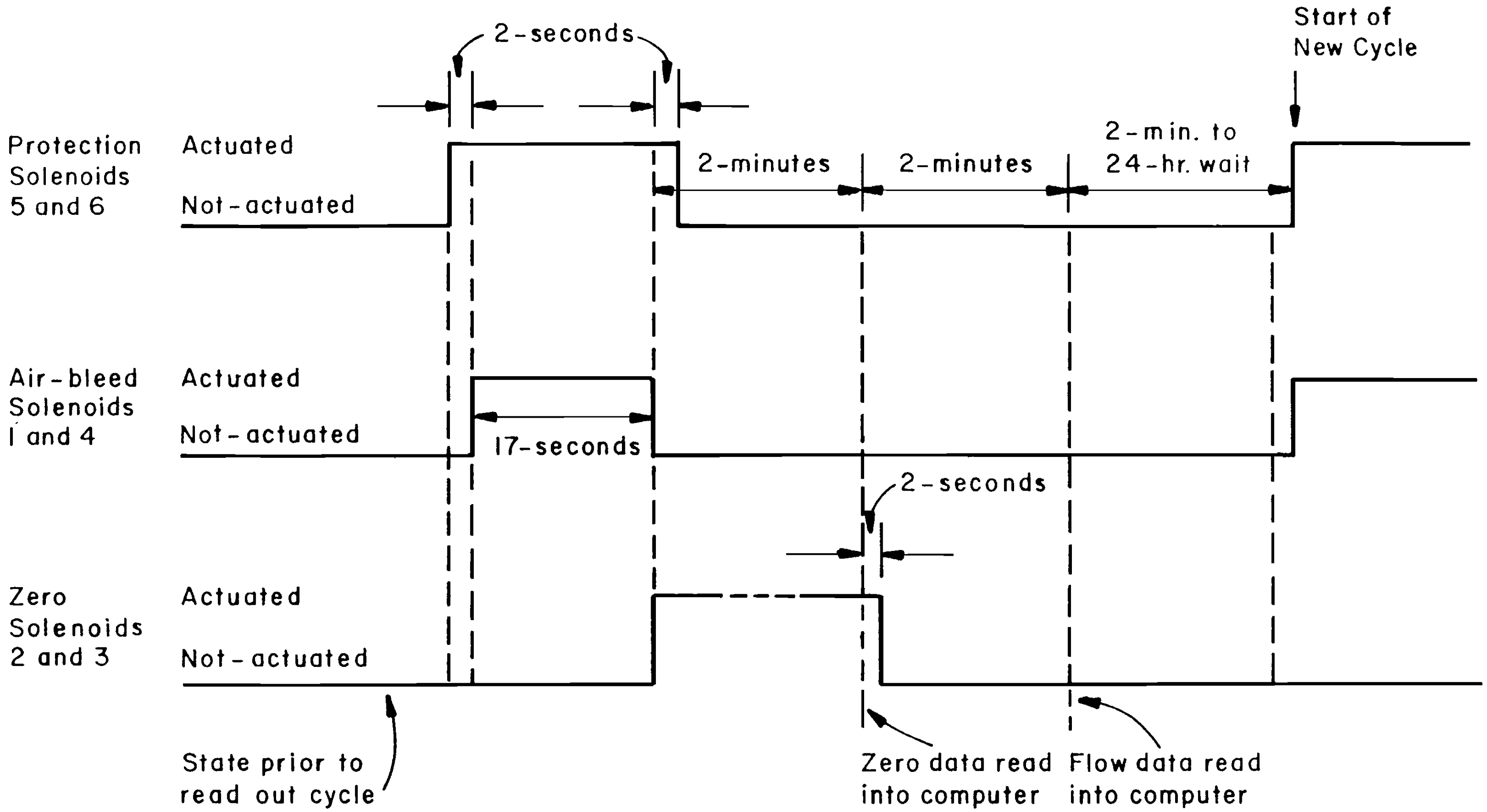
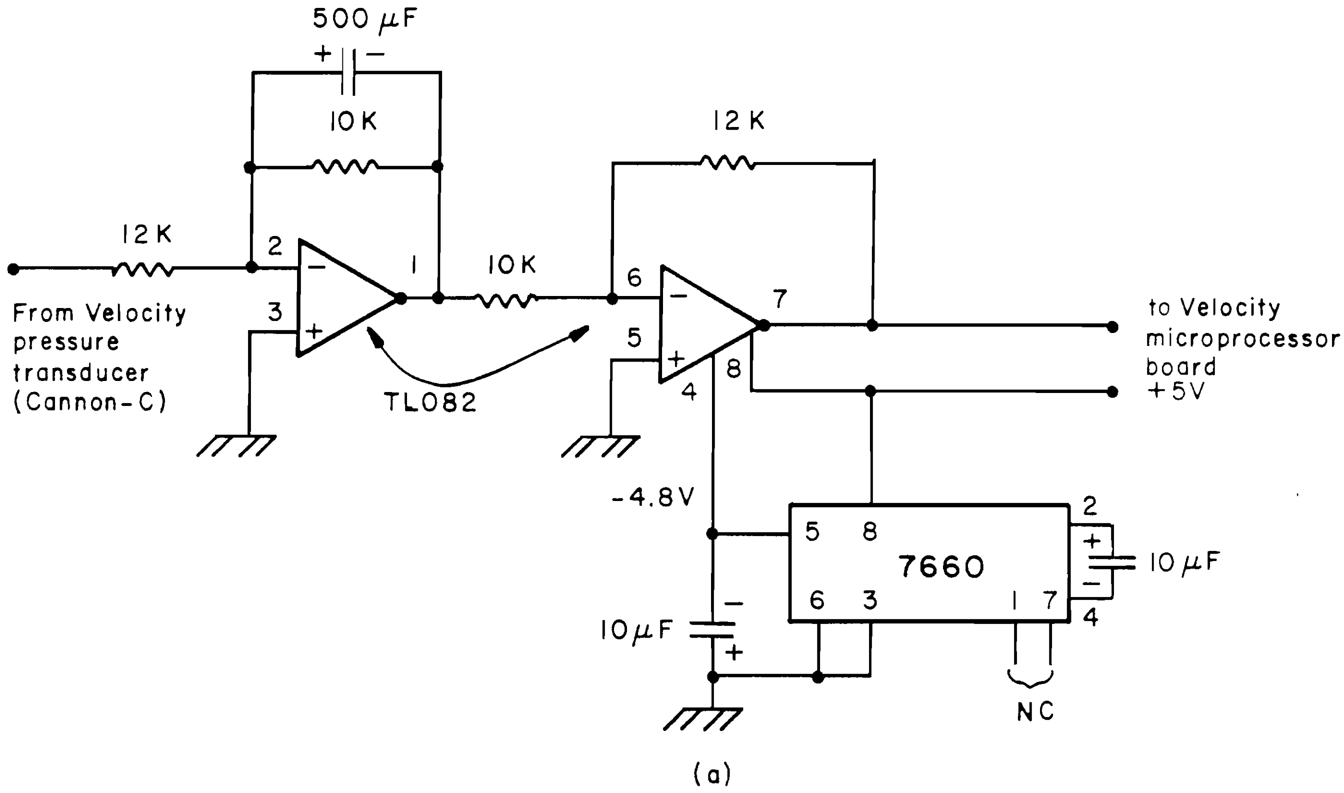


Figure A-23. Solenoid valve timing diagram.



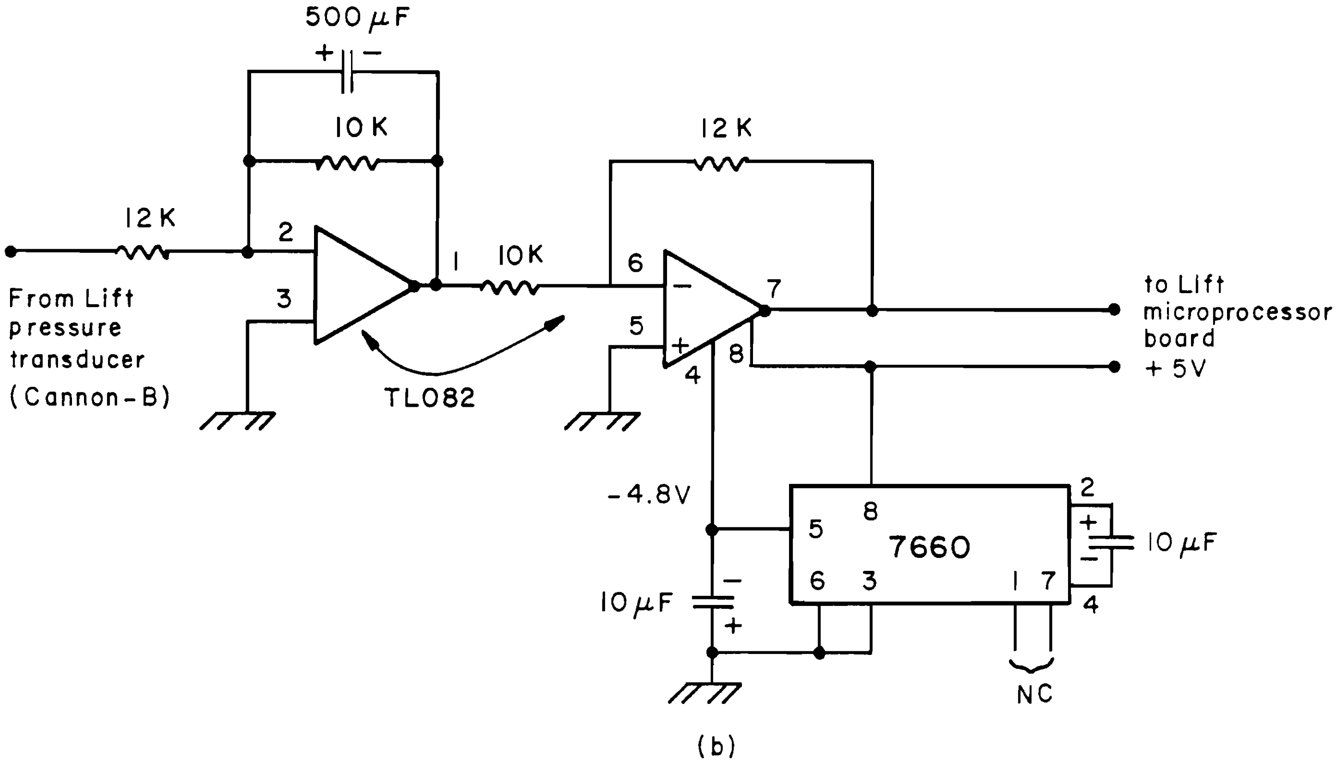


Figure A-24. Smoothing circuitry for (a) velocity and (b) line pressure.

Appendix B

Program Listing for the Automatic Pump Efficiency Monitor as Stored EPROM

```
.Z80
.PHASE 0
;
;
;
;
;
;       *********************************************************
;       *THE PROGRAM COMPUTES THE EFFICIENCY OF AN IRRIGATION  *
;       *PUMPING SYSTEM.  THE EQUATION USED IS AS FOLLOWS:      *
;       *                                                       *
;       * EFFICIENCY (IN %) = (POWER OUT/POWER IN) X 100        *
;       *                                                       *
;       *  =0.0846VA((H + V^2/64.35 + 2.306(DELTA P)) X 100     *
;       *                                                       *
;       *DIVIDED BY (METER FACTOR KH/TIME FOR DISK REVOLUTION) *
;       *                                                       *
;       *  WHERE   V = VELOCITY OF WATER IN PIPE (FEET/SEC)     *
;       *          A = CROSS-SECTIONAL AREA OF PIPE (SQ.  FEET) *
;       *          H = DISTANCE FROM PIPE AXIS TO BOTTOM OF     *
;       *              BUBBLER TUBE (FEET)                      *
;       *  (DELTA P) = PRESSURE DIFFERENCE BETWEEN LINE PRESS. *
;       *              AND BUBBLER PRESSURE(LBS./SQ.INCH)       *
;       * THE METER FACTOR AND DISK REVOLUTION INFORMATION      *
;       * RELATE TO THE KILOWATT-HOUR METER WHICH IS USED AS A *
;       * MEASURE OF THE ELECTRICAL POWER BEING PUT INTO THE    *
;       * SYSTEM.                                               *
;       *********************************************************
;
;
;

;       *************************
;       *EQUATES FOR THE PROGRAM*
;       *************************
;
;
;
KTIM    EQU     082AH
TEMP1   EQU     082CH
POWIN   EQU     082EH
DELTAP  EQU     0830H
PVEL    EQU     0832H
LIFTT   EQU     0836H
PVELD   EQU     0838H
RAMPT   EQU     083CH
DEN     EQU     0848H
NUM     EQU     084AH
FLOWW   EQU     084CH
VELZER  EQU     084EH
PRIFLG  EQU     084FH
KHFACM  EQU     2100H
KHFACL  EQU     2000H
PRESSR  EQU     2300H
HIGHT1  EQU     2100H
HIGHT2  EQU     2200H
VEL     EQU     1C00H
VELM    EQU     1D00H
PIPFAM  EQU     1E00H
PIPFAL  EQU     1F00H
PRITIM  EQU     1E00H
```

```
SIGNUM  EQU     1C00H
RTCFLG  EQU     1C00H
MONMIN  EQU     1000H
RAMBLK  EQU     0860H
RAMNUM  EQU     13H
RAMCNT  EQU     72H
LINCNT  EQU     6
;
;
;       ********************************************************
;       *THE PROGRAM COMMENCES WITH A ZEROING OF THE INITIAL   *
;       *256 BYTES OF RAM AND ALSO THE 12 LED DISPLAYS.        *
;       ********************************************************
;
;
        LD      A,0             ;ZERO ACCUMULATOR
        LD      HL,0800H        ;RAMSTART- STARTING ADDRESS FOR FILL
        LD      B,0             ;FILL 256 BYTES WITH ZEROES
FILL:   LD      (HL),A          ;STORE BYTE
        INC     HL              ;INCREMENT POINTER
        DJNZ    FILL            ;CONTINUE IF B NOT ZERO
        LD      B,0             ;ZERO B REGISTER
        LD      HL,1000H        ;ENTER LED STARTING ADDRESS
NULL:   LD      (HL),B          ;ZERO LED
        INC     H               ;POINT TO NEXT LED ADDRESS
        LD      A,1CH           ;HAVE WE ZEROED ALL LEDS?
        CP      H
        JP      NZ,NULL         ;NO, SO GO BACK
        LD      A,0             ;ZERO ACCUMULATOR
        LD      (PRIFLG),A      ;SET PRINT FLAG FOR INITIATION
;
;
;
;
;       ********************************************************
;       *SET THE STACK POINTER AND SET UP THE COUNTER TIMER CCT*
;       *AS WELL AS THE PARALLEL INPUT/OUTPUT CIRCUITS.        *
;       ********************************************************
;
;
;
;
        LD      SP,0829H        ;SET STACK POINTER TO YIELD 42 BYTES OF STACK
;
        LD      A,0CFH          ;SET UP PIO1 CHANNEL A WITH ALL INPUTS.
        OUT     (0AH),A         ;THIS PIO RECEIVES AN INPUT FROM THE
        LD      A,0FFH          ;PRESSURE (DELTA P) ANALOG TO DIGITAL
        OUT     (0AH),A         ;CONVERTER.
;
;
        LD      A,0CFH          ;SET UP PIO1 CHANNEL B;BITS 0 AND 1 ARE INPUTS,
        OUT     (0BH),A         ;0=KWH METER SWITCH, 1=ZERO/PRINT FLAG, BITS 2
        LD      A,3             ;TO 7 ARE OUTPUTS WITH 2=*56* SOLENOID, 3=*14*
        OUT     (0BH),A         ;SOLENOID, 4,5,6=RTC CONTROL, 7=*23* SOLENOID.
;
;
        LD      A,0CFH          ;SET UP PIO2 CHANNEL B FOR ALL INPUTS
        OUT     (0FH),A         ;THIS PIO IS USED FOR THE VELOCITY A/D
        LD      A,0FFH
        OUT     (0FH),A
;
;
        LD      A,0CFH          ;SET UP PIO3 CHANNEL A FOR ALL OUTPUTS.
        OUT     (12H),A         ;BITS 0 TO 6 ARE PRINTER DATA AND BIT 7 IS
        LD      A,0             ;THE DATA STROBE.
        OUT     (12H),A
```

```
;
;
        LD      A,0CFH          ;SET UP PIO3 CHANNEL B WITH BITS 0 TO 3 AS
        OUT     (13H),A         ;OUTPUTS - RTC ADDRESS; AND BITS 4 TO 7 AS
        LD      A,0F0H          ;INPUTS - RTC DATA
        OUT     (13H),A
;
;
        LD      A,55H           ;COUNTER TIMER CIRCUIT CTC1 CHANNEL 2 COUNTS
        OUT     (2),A           ;SECONDS WITH THE DOWN COUNTER SET AT 100 DEC.
        LD      A,64H
        OUT     (2),A
;
;
        LD      A,55H           ;CTC1 CHANNEL 1 COUNTS ONE HUNDREDTHS OF
        OUT     (1),A           ;SECONDS WITH THE DOWN COUNTER SET AT 100 DEC.
        LD      A,64H           ;CHANNEL 0 OF THIS CTC1 IS SET PRIOR TO THE
        OUT     (1),A           ;ACTUAL TIMING OF THE KWH EVENT.
;
;
;
;       *****************************************************
;       *THE MAIN PROGRAM INVOLVES A SERIES OF SUB-ROUTINE    *
;       *CALLS.                                               *
;       *****************************************************
;
;
;
        CALL    LORTC           ;SET UP REAL TIME CLOCK IF FLAGGED
START:  CALL    RETN            ;WAIT FOR KWH METER TO GO LOW
        CALL    TESTK           ;READ POWER-IN INFORMATION IN
        CALL    PRESS           ;OBTAIN DELTA P INFORMATION
        CALL    VELOC1          ;MEASURE VELOCITY OF WATER
        CALL    LIFT            ;CALCULATE LIFT
        CALL    FLOW            ;CALCULATE FLOW USING VELOCITY AND AREA
        CALL    DISP            ;DISPLAY EFFICIENCY,POWER IN,LIFT,FLOW ON LEDS
        CALL    ZERPRI          ;DO WE WISH TO ZERO/PRINT?
        JP      START           ;GO AROUND AGAIN
;
;
;
;
;
;
;       *****************************************************
;       *THE FOLLOWING ROUTINE TESTS THE STATUS OF THE KWH    *
;       *SWITCH INPUT TO SEE IF IT HAS BEEN FLAGGED HIGH.  IF *
;       *IT HAS, THEN A TIMER (CTC1) IS STARTED TO TIME EIGHT *
;       *REVOLUTIONS OF THE METER DISK.                       *
;       *            A 100 SECOND TIME-OUT IS ALSO USED TO    *
;       *PREVENT AN OVERFLOW; THE TIMING IS ABORTED IN THIS   *
;       *CASE AND WOULD PROBABLY INDICATE THAT THE PUMP IS NOT *
;       *IN OPERATION. THE `POWER-IN` PART OF THE EFFICIENCY  *
;       *EQUATION IS COMPUTED AS (3.6KH/TIME) AND IS STORED IN *
;       *RAM AS 100 TIMES THE ACTUAL VALUE IN LOCATION `POWIN` *
;       *****************************************************
;
;
TESTK:  LD      HL,0FFFFH       ;LOAD OUTER LOOP FOR 100 SECOND TIME-OUT
LPX1:   DEC     HL              ;DECREMENT OUTER LOOP
        LD      B,0FFH          ;LOAD INNER LOOP
LPX2:   DEC     B               ;DECREMENT INNER LOOP
        JP      NZ,LPX2         ;FINISHED INNER LOOP?
        IN      A,(9)           ;IS KWH SWITCH HIGH?
        BIT     0,A             ;TEST BIT 0 = KWH SWITCH INPUT
        JP      NZ,EXZERO       ;IT'S HIGH , SO SERVICE
```

```
         XOR     A               ;CLEAR ACCUMULATOR READY FOR COMPARISONS
         CP      H               ;FINISHED MSBYTE COUNT YET
         JP      NZ,LPX1         ;IF NOT THEN GO BACK
         CP      L               ;FINISHED LSBYTE YET
         JP      NZ,LPX1         ;IF NOT THEN GO BACK
LPX3:    IN      A,(9)           ;100 SECONDS UP SO WAIT TILL HIGH THEN 5 MIN
         BIT     0,A             ;WAIT SO PUMP HAS TIME TO STABILISE
         JP      Z,LPX3
         CALL    FIVMIN          ;WAIT THE FIVE MINUTES
         CALL    RETN            ;ALSO WAIT UNTIL KWH INPUT IS LOW
         JP      TESTK           ;READY FOR ANOTHER KWH TIMING EVENT
EXZERO:  LD      A,35H           ;YES!, INITIALISE CHANNEL 0 OF CTC1 FOR AN
         OUT     (0),A           ;OUTPUT FREQUENCY OF 100HZ
         LD      A,60H           ;DOWN COUNTER LOAD OF 96 DECIMAL
         OUT     (0),A
         IN      A,(2)           ;READ CHANNEL 2 AND STORE IN THE D REGISTER
         LD      D,A             ;D CONTAINS START TIME - SECONDS
         IN      A,(1)           ;READ CHANNEL 1 AND STORE IN THE E REGISTER
         LD      E,A             ;E CONTAINS START TIME - 1/100 TH'S OF SECS
         LD      HL,0FFFFH       ;INITIATE 100 SECOND TIMEOUT FOR KWH
LPX7:    DEC     HL              ;DECREMENT OUTER LOOP
         LD      B,0FFH          ;LOAD INNER LOOP
LPX8:    DEC     B               ;DECREMENT INNER LOOP
         JP      NZ,LPX8         ;INNER COUNT ABOUT 1.5 MILLISECONDS
         IN      A,(9)           ;LOOK AT THE KWH SWITCH INPUT AGAIN
         BIT     0,A
         JP      Z,KFIN          ;IF LOW, NEED TO STOP THE CTC TIMER
         XOR     A               ;CLEAR ACCUMLATOR
         CP      H               ;OUTER LOOP FINISHED?
         JP      NZ,LPX7         ;NO, SO GO BACK TO LPX7 LOOP
         CP      L               ;FINISHED LSBYTE OUTER LOOP YET?
         JP      NZ,LPX7         ;NO, SO GO BACK
         LD      A,3             ;YES! 100 SECS UP SO TURN OFF CHANNEL
         OUT     (0),A
LPX9:    IN      A,(9)           ;LOOK AT THE KWH INPUT AGAIN
         BIT     0,A
         JP      NZ,LPX9         ;IF STILL HIGH (PUMP OFF) THEN KEEP LOOPING
         CALL    FIVMIN          ;PUMP GOING AGAIN SO WAIT 5 MINS TO STABILISE
         CALL    RETN            ;WE NEED TO ENTER THE TESTK ROUTINE WHEN THE
                                 ;INPUT SIGNAL IS LOW SO AS TO BE ABLE TO START
                                 ;THE KWH TIMER AT THE BEGINNING OF THE CYCLE.
         JP      TESTK           ;SWITCH LOW SO AS TO RECORD START PROPERLY.
KFIN:    LD      A,3             ;VALID KWH READING SO TURN CHANNEL 0 OFF.
         OUT     (0),A
         LD      C,2             ;STORE STOP SECONDS IN REGISTER B
         IN      B,(C)
         LD      C,1             ;STORE STOP 1/100 TH'S OF SECS IN REGISTER C
         IN      C,(C)           ;ELAPSED TIME IS TIME FOR 8 REVS OF KWH DISK
         CALL    TIMER           ;COMPUTE ELAPSED TIME IN 1/100 TH'S OF SECONDS
         LD      (KTIM),DE       ;SAVE ELAPSED TIME IN RAM - LOCATION KTIM
         LD      A,(KHFACM)      ;GET 10*KH FACTOR(MSBYTE) OFF SWITCHED ROM'S
         SRL     A               ;RIGHT JUSTIFY TO OBTAIN CORRECT BITS
         SRL     A
         SRL     A
         SRL     A
         SRL     A
         LD      D,A             ;TRANSFER MSBYTE TO D REGISTER
         LD      A,(KHFACL)      ;GET 10*KH FACTOR(LSBYTE) OFF SWITCHED ROM'S
         LD      E,A             ;TRANSFER LSBYTE TO E REGISTER
         LD      BC,7080H        ;LOAD BC WITH 28800 DECIMAL
         CALL    MUL16           ;MULTIPLY - RESULTS IN D,E,H,L REGISTERS
         CALL    REFORM          ;FORMAT FOR DIVIDE
         LD      DE,(KTIM)       ;LOAD DENOMINATOR WITH ELAPSED TIME
         CALL    DIV16           ;DIVIDE (10*KH)*28800 BY (100*KTIME)-RESULT HL
         LD      (POWIN),HL      ;STORE 100*KW IN RAM = POWER IN
         RET
```

```
;
;
;
;
;
;        ******************************************************
;        *THE FOLLOWING ROUTINE READS THE PRESSURE TRANSDUCER  *
;        *VIA AN A/D - THE PRESSURE IS THE DELTA P AS FOUND IN  *
;        *THE LIFT EQUATION:  THIS DELTA P IS MULTIPLIED BY 2.31*
;        *AND THE STORED RESULT IN `DELTAP` IS 10*(DELTA P) WITH*
;        *DELTA P IN UNITS OF FEET.                             *
;        ******************************************************
;
;
;
PRESS:   CALL    STROBE           ;STROBE A/D`S PREPARATORY FOR CONVERSION
         LD      HL,PRESSR        ;LOAD IN PRESSURE RANGE ADDRESS
         LD      B,(HL)           ;GET PRESSURE RANGE OFF SWITCHED ROM`S
         IN      A,(8)            ;GET A/D DATA (DELTA P AS 8-BIT WORD)
         CALL    MUL8             ;ANSWER = (PRANGE*DELTA P) IN HL PAIR
         EX      DE,HL            ;SHIFT INTO DE PAIR
         LD      BC,3E8H          ;MULTIPLICAND IS 1000 DECIMAL
         CALL    MUL16            ;MULTIPLY - RESULT IN D,E,H,L
         CALL    REFORM
         LD      DE,2B5DH         ;DIVIDE BY 11101 DECIMAL
         CALL    DIV16            ;DIVIDE TO GET 10*(DELTA P) IN FEET IN HL PAIR
         LD      (DELTAP),HL      ;STORE THE 10*(DELTA P) RESULT IN RAM
         RET
;
;
;
;
;
;
;        ******************************************************
;        *THIS ROUTINE ZEROS THE VELOCITY PRESSURE TRANSDUCER  *
;        *AND SUBSEQUENTLY  READS IT VIA AN A/D, CALCULATES  THE*
;        *VELOCITY  SQUARED  USING   V=1.548*(SQRT (PRESSURE)). *
;        *RESULT IN PVEL AND PVEL+2 IS 1,000,000*VEL SQUARED.   *
;        *THE VELOCITY READING IS MODIFIED BY THE ZERO READING, *
;        *I.E. READING IS SUBTRACTED FROM THE ACTUAL A/D READING*
;        ******************************************************
;
;
;
;
;
VELOC:   LD      A,4              ;SET BIT 2 OF ACCUMULATOR
         OUT     (9),A            ;SIGNAL TO *56* SOLENOID- PROTECTION
         CALL    BIGCNT           ;WAIT APPROX. 2 SECONDS
         LD      A,0CH            ;SET BITS 2 AND 3 OF ACCUMULATOR
         OUT     (9),A            ;LEAVE *56* ON AND TURN ON *14* SOLENOID-BLEED
         CALL    CNT17            ;WAIT 17 SECONDS
         LD      A,84H            ;LEAVE *56* ON AND TURN ON *23* SOLENOID-ZERO
         OUT     (9),A            ;AND TURN OFF *14* SOLENOID (BLEED FINISHED).
         CALL    BIGCNT           ;WAIT APPROX. 2 SECONDS
         LD      A,80H            ;LEAVE *23* (ZERO SOLENOID) ON AND TURN OFF
         OUT     (9),A            ;*56* PROTECTION SOL. READY FOR ZERO READING
         CALL    CNT17            ;WAIT TWO MINUTES
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    STROBE           ;STROBE A/D'S
```

```
         IN      A,(0DH)          ;READ VELOCITY TRANSDUCER WHILE ZEROED
         LD      (VELZER),A       ;STORE IN RAM FOR FUTURE USE
         LD      A,0              ;RESET *56* SOLENOID
         OUT     (9),A            ;TURN OFF ALL SOLENOIDS
         CALL    CNT17            ;WAIT TWO MINUTES
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    CNT17
         CALL    STROBE           ;STROBE A/D'S
         LD      A,(VEL)          ;LOAD IN VELOCITY RANGE MSBYTE OFF SWITCHED ROM
         AND     0FH              ;MASK FOR PERTINENT BITS
         LD      B,A              ;PUT MSBYTE IN B
         LD      HL,VELM          ;GET LSBYTE VELOCITY RANGE ADDRESS
         LD      C,(HL)           ;LOAD LSBYTE IN C
         LD      A,(VELZER)       ;GET ZERO VELOCITY PRESSURE READING
         LD      E,A              ;STORE IN E REGISTER
         IN      A,(0DH)          ;GET A/D DATA (VELOCITY PRESSURE A/D)
         SUB     E                ;ACC. HOLDS ACTUAL READING MINUS ZERO READING
         LD      E,A              ;LOAD INTO E REGISTER
         LD      D,0              ;ZERO D READY FOR MULTIPLY
         CALL    MUL16            ;RESULT IN D,E,H,L
         CALL    REFORM
         LD      DE,100H          ;DIVIDE BY 256 DECIMAL
         CALL    DIV16            ;RESULT IN HL PAIR IS 100*PRESSURE(VEL)
         EX      DE,HL            ;PUT RESULT INTO DE
         LD      BC,5D9BH         ;MULTIPLY BY 23963 DECIMAL
         CALL    MUL16            ;RESULT IN D,E,H,L IS 1,000,000*VEL SQUARED
         LD      A,E              ;STORE MSWORD IN PVEL. FIRST SWITCH D AND E
         LD      E,D
         LD      D,A
         LD      (PVEL),DE
         LD      A,L              ;STORE LSWORD IN PVEL+2. SWITCH H AND L FIRST.
         LD      L,H
         LD      H,A
         LD      (PVEL+2),HL
         RET
;
;
;
;
;        ******************************************************
;        *THIS ROUTINE READS THE VELOCITY TRANSDUCER VIA AN A/D,*
;        *CALCULATING THE VELOCITY  SQUARED  USING             *
;        *          V=1.548*(SQRT (PRESSURE)).                 *
;        *RESULT IN PVEL AND PVEL+2 IS 1,000,000*VEL SQUARED.  *
;        ******************************************************
;
;
;
;
;
VELOC1:  LD      A,0              ;RESET ALL BITS OF ACCUMULATOR
         OUT     (9),A            ;SIGNAL TO DE-ENERGIZE SOLENOIDS
         CALL    STROBE           ;STROBE A/D'S
         LD      A,(VEL)          ;LOAD IN VELOCITY RANGE MSBYTE OFF SWITCHED ROM
         AND     0FH              ;MASK FOR PERTINENT BITS
         LD      B,A              ;PUT MSBYTE IN B
         LD      HL,VELM          ;GET LSBYTE VELOCITY RANGE ADDRESS
         LD      C,(HL)           ;LOAD LSBYTE IN C
         LD      A,(VELZER)       ;GET ZERO VELOCITY PRESSURE READING
         LD      E,A              ;STORE IN E REGISTER
         IN      A,(0DH)          ;GET A/D DATA (VELOCITY PRESSURE A/D)
         SUB     E                ;ACC. HOLDS ACTUAL READING MINUS ZERO READING
```

```
        LD      E,A            ;LOAD INTO E REGISTER
        LD      D,0            ;ZERO D READY FOR MULTIPLY
        CALL    MUL16          ;RESULT IN D,E,H,L
        CALL    REFORM
        LD      DE,100H        ;DIVIDE BY 256 DECIMAL
        CALL    DIV16          ;RESULT IN HL PAIR IS 100*PRESSURE(VEL)
        EX      DE,HL          ;PUT RESULT INTO DE
        LD      BC,5D9BH       ;MULTIPLY BY 23963 DECIMAL
        CALL    MUL16          ;RESULT IN D,E,H,L IS 1,000,000*VEL SQUARED
        LD      A,E            ;STORE MSWORD IN PVEL. FIRST SWITCH D AND E
        LD      E,D
        LD      D,A
        LD      (PVEL),DE
        LD      A,L            ;STORE LSWORD IN PVEL+2. SWITCH H AND L FIRST.
        LD      L,H
        LD      H,A
        LD      (PVEL+2),HL
        RET
;
;
;       ******************************************************
;       *THE LIFT IS CALCULATED HERE AS PER THE EQUATION BELOW:*
;       *THIS ROUTINE FOLLOWS THE VELOCITY ROUTINE IN THAT THE *
;       *D,E,H,L REGISTERS CONTAIN THE VELOCITY SQUARED RESULTS*
;       *AT THE END OF THAT ROUTINE AND THE V^2/64.35 TERM IN  *
;       *THE LIFT EQUATION CAN READILY UTILISE THE VELOCITY IN *
;       *IT`S SQUARED FORM.                                    *
;       *                                                      *
;       *  LIFT = (HEIGHT + V^2/64.35 + 2.31*(DELTA P))        *
;       ******************************************************
;
;
;
;
LIFT:   CALL    REFORM         ;FORMAT D,E,H,L FROM VEL ROUTINE READY FOR DIV.
        LD      DE,1923H       ;DIVIDE BY 6435 DECIMAL
        CALL    DIV16          ;RESULT IS 10000*(V^2/64.35)
        LD      DE,0           ;ZERO DE READY FOR ANOTHER DIVIDE
        CALL    REFORM
        LD      DE,3E8H        ;DIVISOR IS 1000 DECIMAL
        CALL    DIV16          ;RESULT IN HL IS 10*(V^2/64.35)
        LD      DE,(DELTAP)    ;GET 10*(DELTA P) PRESSURE RESULT FROM RAM
        ADD     HL,DE          ;HL = 10*(V^2/64.35 + 2.31*(DELTA P))
        LD      A,(HIGHT1)     ;GET MSBYTE HEIGHT,H OFF SWITCHED ROM`S
        AND     1FH            ;MASK 5 LOWER BITS
        LD      D,A            ;PASS TO D REGISTER
        LD      A,(HIGHT2)     ;GET LSBYTE OF HEIGHT,H FROM SWITCHED ROM`S
        LD      E,A
        ADD     HL,DE          ;HL HAS 10*(H + V^2/64.35 + 2.31*(DELTA P)
                               ;WHICH EQUALS 10*LIFT
        LD      (LIFTT),HL     ;STORE 10*LIFT IN RAM LOCATION `LIFTT`
        RET
;
;
;
;
;       ******************************************************
;       *THE FLOW IS CALCULATED FROM THE VELOCITY USING THE    *
;       *SIMPLE EQUATION FLOW =(VELOCITY)*(CROSS-SECTIONAL AREA*
;       *OF THE PIPE).  INITIALLY THE VELOCITY IS FOUND BY TAK-*
;       *ING THE SQUARE ROOT OF 1,000,000*V^2 BY AN ITERATIVE  *
;       *INCREMENTAL METHOD. ONCE THE FLOW IS FOUND THE WAY IS *
;       *OPEN TO CALCULATE THE EFFICIENCY BY THE EQUATION:     *
;       *                                                      *
;       *    EFFICIENCY = (0.0846*FLOW*LIFT/(POWER IN))*100%   *
;       *                                                      *
```

```
;       *THE RESULT IS LEFT IN THE HL REG AS 10*EFFICIENCY IN %*
;       ********************************************************
;
;
;
;
FLOW:   LD      DE,0            ;START SQUARE ROOT AT 0
SAME:   PUSH    DE              ;MAKE COPY ON STACK
        PUSH    DE              ;MAKE ANOTHER COPY
        POP     BC              ;TRANSFER DE TO BC VIA STACK
        CALL    MUL16           ;FIND SQUARE OF NUMBER - DEHL = DE*BC
        LD      A,E             ;NEXT THREE INSTRUCTIONS EXCHANGE D AND E REG'S
        LD      E,D
        LD      D,A
        LD      (PVELD),DE      ;SAVE MSWORD IN RAM LOCATION PVELD
        LD      A,L             ;NEXT THREE INSTRUCTIONS EXCHANGE H AND L REG'S
        LD      L,H
        LD      H,A
        LD      (PVELD+2),HL    ;SAVE LSWORD IN RAM LOCATION PVELD+2
        LD      DE,PVEL         ;GET ADDRESS OF 1,000,000*V^2 - MSBYTE
        LD      HL,PVELD        ;GET ADDRESS OF TRIAL SQUARED NUMBER - MSBYTE
        LD      C,4             ;NUMBER OF BYTES FOR MULTIPLE BYTE SUBTRACT
        CALL    MULSUB          ;SUBTRACT IN MULTIPLE BYTE FASHON
        JP      C,OVERR         ;CHECK TO SEE IF RESULT IS MORE THAN SOURCE
        POP     DE              ;IF NO THEN GET THE OLD SQUARE ROOT BACK
        INC     DE              ;OLD VALUE IS INCREMENTED FOR NEXT RUN
        JP      SAME            ;BACK AGAIN FOR ANOTHER RUN
OVERR:  POP     DE              ;YES, WE'VE GONE TOO FAR SO GET OLD SQRT BACK
        DEC     DE              ;OLD VALUE MINUS ONE IS 1000*(SQUARE ROOT(V^2))
        LD      A,(PIPFAM)      ;LOAD MSBYTE OF PIPE FACTOR
        AND     7               ;MASK FOR LOWER 3 BITS
        LD      B,A
        LD      A,(PIPFAL)      ;LOAD LSBYTE OF PIPE FACTOR = 1000*ACTUAL VALUE
        LD      C,A
        CALL    MUL16           ;RESULT IN DEHL IS 1,000,000*FLOW
        CALL    REFORM
        LD      DE,3E8H         ;DIVISOR IS 1000 DECIMAL
        CALL    DIV16           ;RESULT IN HL IS 1000*FLOW
        EX      DE,HL           ;PUT IN DE
        LD      (FLOWW),DE      ;STORE 1000*FLOW IN RAM LOCATION 'FLOWW'
        LD      BC,(LIFTT)      ;GET 10*LIFT - MULTIPLIER
        CALL    MUL16           ;RESULT IS 10,000*FLOW*LIFT IN DEHL
        CALL    REFORM
        LD      DE,(POWIN)      ;GET 100*POWER IN
        CALL    DIV16           ;RESULT IN HL PAIR IS 100*(FLOW*LIFT/KW)
        EX      DE,HL           ;PUT IN DE
        LD      BC,34EH         ;MULTIPLIER IS 846 DECIMAL
        CALL    MUL16           ;RESULT IN DEHL IS 10,000*EFFICIENCY
        CALL    REFORM
        LD      DE,3E8H         ;DIVIDE BY 1000 DECIMAL
        CALL    DIV16           ;RESULT IN HL PAIR IS 10*EFFICIENCY
        RET
;
;
;
;
;
;       ********************************************************
;       *THIS ROUTINE CONVERTS THE EFFICIENCY,  POWER IN,  LIFT*
;       *AND FLOW RESULTS INTO A BCD FORMAT AND DISPLAYS THE   *
;       *SAME ON THE LEDS; THE BCD RESULTS ARE ALSO STORED IN  *
;       *RAM TO AWAIT PRINTING. NOTE THAT THIS ROUTINE IS TO   *
;       *FOLLOW THE FLOW ROUTINE AS THE EFFICIENCY RESULT IS   *
;       *PASSED TO THIS ROUTINE VIA THE HL REGISTER.           *
;       ********************************************************
;
```

```
;
;
;
;
DISP:   LD      IX,RAMPT          ;LOAD IN RAM BCD BLOCK START
        LD      IY,1200H          ;LOAD IN EFFICIENCY LED ADDRESS - MSNIBBLE
        CALL    BCDCON            ;CONVERT TO BCD AND DISPLAY THE RESULT
        EXX
        LD      BC,(POWIN)        ;BRING 100*POWER IN INTO B'C' READY FOR DIVIDE
        EXX
        LD      HL,0              ;ZERO MSWORD READY FOR DIVIDE
        LD      DE,0AH            ;DIVISOR IS 10 DECIMAL
        CALL    DIV16             ;HL PAIR CONTAINS 10*POWER IN
        LD      IX,RAMPT+3        ;RAM BCD LOCATION
        LD      IY,1500H          ;ADDRESS OF POWER IN MS LED LOCATION
        CALL    BCDCON            ;DISPLAY POWER IN AND STORE THE RESULT IN RAM
        EXX
        LD      BC,(LIFTT)        ;GET 10*LIFT RESULTS AND LOAD IN B'C'
        EXX
        LD      HL,0
        LD      DE,0AH            ;DIVIDE BY 10 DECIMAL TO GET ACTUAL LIFT
        CALL    DIV16
        LD      IX,RAMPT+6        ;RAM BCD LOCATION
        LD      IY,1800H          ;ADDRESS OF LIFT MS LED LOCATION
        CALL    BCDCON            ;DISPLAY AND STORE THE LIFT RESULT
        EXX
        LD      BC,(FLOWW)        ;GET THE 1000*FLOW RESULTS
        EXX
        LD      HL,0
        LD      DE,0AH            ;AGAIN DIVIDE BY 10 DECIMAL TO GET 100*FLOW
        CALL    DIV16
        LD      IX,RAMPT+9        ;RAM BCD LOCATION
        LD      IY,1B00H          ;ADDRESS OF FLOW MS LED LOCATION
        CALL    BCDCON            ;DISPLAY AND STORE THE FLOW RESULTS
        RET
;
;
;
;
;       *******************************************************
;       *THIS ROUTINE CHANNELS INFORMATION TO A PRINT BLOCK. ON*
;       *COMMAND FROM THE REAL TIME CLOCK THIS PRINT BLOCK WILL*
;       *BE SENT TO THE PRINTER SO AS TO OBTAIN A PERMANENT    *
;       *COPY OF EFFICIENCY,  POWER IN,  LIFT,  AND  FLOW AS   *
;       *WELL AS SITE NUMBER AND REAL TIME CLOCK INFORMATION.  *
;       *******************************************************
;
;
;
SITE:   CALL    BLOCK             ;COPY ROM PRINT BLOCK TO RAM PRINT BLOCK
        LD      A,(SITNUM)        ;LOAD SITE NUMBER FROM SWITCHED ROM INTO ACC.
        SRL     A                 ;RIGHT JUSTIFY
        SRL     A
        SRL     A
        SRL     A
        RES     5,A               ;BLANK OUT RTC FLAG SWITCH
        ADD     A,30H             ;CONVERT SITE NUMBER TO ASCII FORMAT
        LD      HL,RAMBLK+5       ;LOAD PRINT BLOCK ADDRESS FOR SITE NUMBER
        LD      (HL),A            ;PUT THE SITE NUMBER INFORMATION IN THE P/B
        LD      HL,RAMBLK+11H     ;NEXT PRINT BLOCK LOCATION - TENS OF YEARS
        LD      B,0CH             ;POINT TO TENS OF YEARS IN RTC
        CALL    REDCLK            ;READ TENS OF YEARS FROM RTC
        ADD     A,30H             ;CONVERT TO ASCII FORMAT
        LD      (HL),A            ;LOAD TENS OF YEARS INTO PRINT BLOCK
        INC     HL                ;POINT TO ADDRESS OF YEARS UNITS IN PRINT BLOCK
        DEC     B                 ;NOW POINT TO YEARS UNITS IN RTC
```

```
        CALL    REDCLK          ;READ FROM RTC
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD YEARS UNITS INTO PRINT BLOCK
        LD      IX,MONTH        ;TABLE POINTER FOR MONTHS
        DEC     B               ;NEXT RTC ADDRESS - MONTH TENS
        DEC     HL              ;NEXT PRINT BLOCK ADDRESS
        DEC     HL
        DEC     HL
        DEC     HL
        DEC     HL
        LD      E,0             ;ZERO E - IF NO DATE TENS THEN UNCHANGED
        CALL    REDCLK          ;READ THE RTC INFORMATION FOR MONTH
        BIT     0,A             ;IS THE MONTH OCTOBER,NOVEMBER OR DECEMBER
        JP      Z,MTH           ;IF IT ISN`T THEN JUMP
        LD      E,0AH           ;IF DATE TENS THEN CHANGE E TO 10 DECIMAL
MTH:    DEC     B               ;NEXT RTC ADDRESS - MONTH UNITS
        CALL    REDCLK          ;LOOK AT MONTH UNITS IN RTC
        ADD     A,E             ;ADD 10 ON TO UNITS IF BIT 0 SET FROM TENS
        LD      E,A             ;HAVE NUMBER OF MONTH - 1=JAN ETC -LOAD IN E
        ADD     A,A             ;DOUBLE A
        ADD     A,E             ;TRIPLE A
        LD      D,0             ;ZERO D REGISTER
        LD      E,A             ;PUT TRIPLED MONTH NUMBER BACK IN E
        ADD     IX,DE           ;ADD TRIPLED NUMBER TO MONTH TABLE POINTER
        LD      A,(IX)          ;IX CONTAINS OFFSET - LOAD FIRST LETTER INTO A
        LD      (HL),A          ;LOAD FIRST LETTER INTO PRINT BLOCK
        INC     HL              ;NEXT PRINT BLOCK ADDRESS
        INC     IX              ;NEXT MONTH TABLE POINTER ADDRESS
        LD      A,(IX)          ;LOAD ACC. WITH NEXT LETTER
        LD      (HL),A          ;LOAD SECOND LETTER INTO PRINT BLOCK
        INC     HL              ;SIMILARLY FOR THIRD LETTER
        INC     IX
        LD      A,(IX)          ;LOAD ACC. WITH THIRD LETTER
        LD      (HL),A          ;LOAD THIRD LETTER INTO PRINT BLOCK
        DEC     HL              ;MOVE TO NEXT PRINT BLOCK ADDRESS - DATE
        DEC     HL
        DEC     HL
        DEC     HL
        DEC     HL              ;POINT TO IN PRINT BLOCK
        DEC     B               ;LOOK AT TENS OF DATE IN RTC
        CALL    REDCLK          ;READ TENS OF DATE
        AND     3               ;MASK FOR 2 LOW SIGNIFICANT BITS
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD TENS OF DATE INTO PRINT BLOCK
        INC     HL              ;NEXT PRINT BLOCK ADDRESS
        DEC     B               ;LOOK AT DATE UNITS IN RTC
        CALL    REDCLK          ;READ THE RTC FOR DATE UNITS
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD DATE UNITS IN PRINT BLOCK
        LD      IX,WKDAY        ;POINT TO WEEKDAY TABLE START
        DEC     HL              ;POINT TO WEEKDAY IN PRINT BLOCK
        DEC     HL
        DEC     HL
        DEC     HL
        DEC     B               ;POINT TO WEEKDAY LOCATION IN RTC
        CALL    REDCLK          ;READ THE WEEKDAY INFORMATION FROM RTC
        ADD     A,A             ;DOUBLE A
        LD      D,0             ;ZERO OUT D REGISTER
        LD      E,A             ;TRANSFER DOUBLED WEEKDAY INFORMATION INTO E
        ADD     IX,DE           ;IX NOW CONTAINS OFFSET FOR WEEKDAY LETTERS
        LD      A,(IX)          ;LOAD ASCII VALUE OF FIRST WEEKDAY LETTER TO A
        LD      (HL),A          ;PUT THAT FIRST LETTER INTO THE PRINT BLOCK
        INC     HL              ;POINT TO SECOND LETTER LOCATION IN PRINT BLOCK
        INC     IX              ;POINT TO NEXT LETTER OF WEEKDAY TABLE
        LD      A,(IX)          ;LOAD SECOND LETTER INTO PRINT BLOCK
        LD      (HL),A          ;LOAD INTO PRINT BLOCK
```

```
        LD      HL,RAMBLK+1FH     ;SET UP PRINT BLOCK FOR SECONDS UNITS
        LD      B,0               ;SET UP RTC ADDRESS POINTER FOR SECONDS UNITS
        CALL    HR                ;LOAD SECONDS UNITS AND SECONDS TENS
        CALL    HR                ;LOAD MINUTES UNITS AND MINUTES TENS
        CALL    HRMOD             ;LOAD HOURS UNITS AND HOURS TENS
        LD      IX,RAMPT          ;POINT TO START OF BCD CONVERTED VARIABLES
        LD      C,0CH             ;SET COUNTER TO 12 DECIMAL - I.E. WE ARE GOING
NEXT:   LD      A,(IX)            ;TO READ IN EFF,POWERIN,LIFT,FLOW. (IX) TO ACC.
        ADD     A,30H             ;ASCII-IZE
        LD      (IX),A            ;PUT ASCII CONVERTED DATA BACK INTO LOCATION
        INC     IX                ;NEXT LOCATION
        DEC     C                 ;DECREMENT COUNTER
        JP      NZ,NEXT           ;LOOP UNTIL ALL VARIABLES ASCII-IZED
        LD      HL,RAMPT          ;START OF VARIABLE LOCATION IN RAM
        LD      DE,RAMBLK+34H     ;PRINT BLOCK LOCATION FOR MSDIGIT - EFFICIENCY
        LDI                       ;LOAD MSDIGIT - EFFICIENCY
        LDI                       ;LOAD MIDDLE DIGIT - EFFICIENCY
        INC     DE                ;BUMP POINTER IN PRINT BLOCK
        LDI                       ;LOAD LSDIGIT - EFFICIENCY
        LD      HL,RAMPT+3        ;POWER IN RAM LOCATION
        LD      DE,RAMBLK+47H     ;PRINT BLOCK LOCATION FOR MSDIGIT - POWER IN
        LDI                       ;LOAD IN POWER IN AS DONE FOR EFFICIENCY
        LDI
        INC     DE
        LDI
        LD      HL,RAMPT+6        ;SAME FOR LIFT
        LD      DE,RAMBLK+59H
        LDI
        LDI
        LDI
        LD      HL,RAMPT+9        ;AND ALSO FOR FLOW
        LD      DE,RAMBLK+6EH
        LDI
        INC     DE
        LDI
        LDI
        LD      HL,RAMBLK         ;POINT TO START OF PRINT BLOCK
        LD      B,LINCNT          ;NUMBER OF LINES TO PRINT
PRINT:  LD      C,RAMNUM          ;NUMBER OF BYTES PER LINE TO PRINT
PRMORE: LD      A,0               ;ZERO THE ACCUMULATOR
        OUT     (10H),A           ;PULSE THE DATA STROBE LOW
        CALL    COUNT             ;STROBE LOW FOR A TIME
        LD      A,(HL)            ;GET THE CHARACTER FROM THE PRINT BLOCK
        SET     7,A               ;SET THE DATA STROBE HIGH ON EACH CHARACTER
        OUT     (10H),A           ;SEND TO PRINTER FOR PRINTING
        CALL    COUNT             ;WAIT A SHORT TIME
        INC     HL                ;NEXT PRINT BLOCK LOCATION
        DEC     C                 ;FINISHED ALL BYTES?
        JP      NZ,PRMORE         ;GO BACK FOR MORE PRINTING
        LD      A,0               ;ZERO THE ACCUMULATOR
        OUT     (10H),A           ;PULSE THE DATA STROBE LOW
        CALL    COUNT             ;WAIT
        LD      A,8DH             ;CARRIAGE RETURN
        OUT     (10H),A
        CALL    BIGCNT            ;WAIT A BIT LONGER
        DEC     B                 ;FINISHED ALL LINES?
        JP      NZ,PRINT          ;GO BACK IF NOT
        LD      A,0
        OUT     (10H),A
        CALL    COUNT
        LD      A,8DH             ;DO A CARRIAGE RETURN
        OUT     (10H),A
        CALL    BIGCNT
        RET
;
;
```

```
;
;
;       ********************************************************
;       *THE REDCLK ROUTINE READS THE REAL TIME CLOCK.         *
;       ********************************************************
;
;
;
;
REDCLK: LD      A,10H           ;STROBE HOLD LINE
        OUT     (9),A
        LD      A,30H           ;WAIT A SHORT TIME
MN:     DEC     A
        JP      NZ,MN
        LD      A,B             ;GET ADDRESS FROM B REGISTER
        OUT     (11H),A         ;SEND ADDRESS TO RTC
        LD      A,40H           ;STROBE READ LINE ON RTC
        OUT     (9),A
        NOP                     ;WAIT A REAL SHORT TIME
        NOP
        NOP
        NOP
        NOP
        IN      A,(11H)         ;GET THE DATA FROM THE RTC
        AND     0F0H            ;MASK FOR THE MSNIBBLE
        SRL     A               ;RIGHT JUSTIFY
        SRL     A
        SRL     A
        SRL     A
        LD      C,A             ;STORE RESULT TEMPORARILY
        LD      A,0             ;ZERO ACCUMULATOR
        OUT     (9),A           ;PUT ALL RTC CONTROL LINES LOW
        LD      A,C             ;GET RESULT BACK
        RET
;
;
;
;
;
;       ********************************************************
;       *THE HR AND HRMOD ROUTINES UTILISE THE REDCLK ROUTINE  *
;       *TO READ THE RTC BUT FURTHER MANIPULATE THE RTC DATA TO*
;       *THE CORRECT FORMAT.  THE DATA IS ALSO ASCII-IZED AND  *
;       *LOADED INTO THE PRINT BLOCK.                          *
;       ********************************************************
;
;
;
HR:     CALL    REDCLK          ;READ THE REAL TIME CLOCK UNITS
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD INTO THE PRINT BLOCK
        DEC     HL              ;NEXT PRINT BLOCK ADDRESS
        INC     B               ;NEXT RTC ADDRESS
        CALL    REDCLK          ;READ THE TENS FROM THE RTC
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD INTO THE PRINT BLOCK
        DEC     HL              ;SET UP P/B ADDRESS FOR START OF NEXT CALL
        DEC     HL
        INC     B               ;SET UP RTC ADDRESS FOR START OF NEXT CALL
        RET
;
;
;
;
HRMOD:  CALL    REDCLK          ;READ RTC UNITS OF HOUR
        ADD     A,30H           ;ASCII-IZE
```

```
        LD      (HL),A          ;LOAD P/B
        DEC     HL              ;NEXT P/B ADDRESS
        INC     B               ;NEXT RTC ADDRESS
        CALL    REDCLK          ;READ RTC TENS OF HOURS
        AND     3H              ;MASK FOR THE LOWER 2 BITS
        ADD     A,30H           ;ASCII-IZE
        LD      (HL),A          ;LOAD P/B
        RET
;
;
;
;
;       ********************************************************
;       *THE FOLLOWING TIMER ROUTINE ALLOWS READING OF THE CTC *
;       *TIMING CIRCUIT SO THAT THE ELAPSED TIME BETWEEN A     *
;       *START AND STOP PULSE CAN BE MEASURED.  THE TIME IN    *
;       *HUNDEREDTHS OF A SECOND IS RETURNED IN THE DE REG PAIR*
;       ********************************************************
;
;
;
TIMER:  LD      A,D             ;TRANSFER MSBYTE OF START TIME TO ACCUMULATOR
        SUB     B               ;SUBTRACT MSBYTE OF STOP TIME
        JP      P,POS           ;IF SIGN POSITIVE THEN JUMP
        LD      HL,6364H        ;LOAD HL WITH 99.100, I.E. H=99 AND L=100
        OR      A               ;REFORMAT TO FIND DIFFERENCE. RESET CARRY
        SBC     HL,BC           ;SUBTRACT BC FROM HL
        ADD     HL,DE           ;ADD RESULT TO START TIME TO GET DIFFERENCE
        JP      FIN             ;DONE FOR NOW
POS:    LD      A,E             ;GET LSBYTE OF START TIME
        SUB     C               ;SUBTRACT LSBYTE OF STOP TIME FROM START LSBYTE
        JP      P,POS1          ;IF POSITIVE SIGN THEN JUMP
        LD      A,E             ;OTHERWISE GET LSBYTE OF START TIME BACK
        ADD     A,64H           ;ADD 100 DECIMAL TO ACCUMULATOR
        LD      E,A             ;PUT BACK IN E REGISTER
        INC     B               ;COMPENSATE FOR 100 ADD BY ADD TO MSBYTE STOP T
        JP      TIMER           ;RECYCLE
POS1:   EX      DE,HL           ;SWITCH START AND STOP TIMES
        OR      A               ;RESET CARRY BIT
        SBC     HL,BC           ;SUBTRACT REFORMATTED TIMES
        LD      A,L             ;GET LSBYTE OF RESULT
        SUB     64H             ;SUBTRACT 100 DECIMAL
        JP      M,FIN           ;IF NEGATIVE SIGN THEN BRANCH
        LD      L,A             ;OTHERWISE LOAD BACK IN L
        INC     H               ;INCREMENT MSBYTE OF RESULT
FIN:    EX      DE,HL           ;PUT RESULT OF X.YZ FORMAT SECS INTO DE PAIR
        LD      A,D             ;GET MULTIPLIER TO ACC (I.E. NUMBER OF SECONDS)
        LD      B,64H           ;LOAD MULTILPLICAND OF 100 DECIMAL INTO B REG
        CALL    MUL8            ;MULTIPLY
        LD      D,0             ;ZERO D REGISTER IN PREPARATION FOR ADD
        ADD     HL,DE           ;HL CONTAINS HUNDREDTHS OF SECONDS ELAPSED
        EX      DE,HL           ;PUT RESULT INTO DE REGISTER FOR RETURN
        RET
;
;
;
;
;       ********************************************************
;       *THE FOLLOWING MULTIPLY ROUTINE HAS THE MULTIPLIER IN  *
;       *THE ACCUMULATOR AND MULTIPLICAND IN THE B REGISTER. IT*
;       *IS AN UNSIGNED 8BIT X 8BIT ROUTINE WITH THE 16BIT RES-*
;       *ULT ENDING UP IN THE HL REGISTER.                     *
;       ********************************************************
;
;
;
```

```
;
MUL8:   LD      L,0             ;CLEAR L
        LD      H,A             ;MULTIPLIER TO H
        LD      C,B             ;MULTIPLICAND TO C
        LD      B,0             ;CLEAR B
        LD      A,8             ;ITERATION COUNT
LOOP4:  ADD     HL,HL           ;SHIFT LEFT ONE BIT
        JP      NC,JUMP1        ;GO IF NO CARRY
        ADD     HL,BC           ;ADD MULTIPLICAND TO PARTIAL PRODUCT
JUMP1:  DEC     A               ;DECREMENT COUNT
        JP      NZ,LOOP4        ;GO IF NOT 8 ITERATIONS
        RET
;
;
;
;
;       *********************************************************
;       *THIS 16BIT X 16BIT UNSIGNED MULTIPLY MULTIPLIES THE    *
;       *CONTENTS OF THE DE AND BC REGISTERS AND RETURNS THE    *
;       *RESULT IN THE DEHL PAIRS                               *
;       *********************************************************
;
;
;
;
MUL16:  LD      A,10H           ;ITERATION COUNTER
        LD      HL,0            ;ZERO PRODUCT
CYCL:   EX      DE,HL           ;EXCHANGE
        ADD     HL,HL           ;SHIFT LEFT ONE BIT
        PUSH    AF              ;SAVE CARRY
        EX      DE,HL           ;EXCHANGE
        ADD     HL,HL           ;SHIFT LEFT ONE BIT
        JP      NC,JUMP2        ;GO IF NO CARRY
        INC     DE              ;CARRY TO MSBYTES
JUMP2:  POP     AF              ;GET CARRY
        JP      NC,JUMP3        ;GO IF NO CARRY
        ADD     HL,BC           ;ADD MULTIPLICAND
        JP      NC,JUMP3        ;GO IF NO CARRY
        INC     DE              ;CARRY TO MSBYTES
JUMP3:  DEC     A               ;DECREMENT ITERATION COUNT
        RET     Z               ;RETURN IF DONE - RESULT IN DEHL
        JP      CYCL            ;CONTINUE
;
;
;
;
;       *********************************************************
;       *THE FOLLOWING ROUTINE STROBES THE ANALOG TO DIGITAL    *
;       *CONVERTERS - MEMORY MAPPED ADDRESS IS 2400H.           *
;       *********************************************************
;
;
;
;
STROBE: LD      A,(2400H)       ;STOBE A/D'S
        LD      DE,20H          ;USE DELAY TIMER TO MEET CONVERTER SET UP
LOOPW2: DEC     DE              ;AND CONVERSION TIMES
        LD      A,0FFH
CIRC2:  DEC     A
        JP      NZ,CIRC2
        XOR     A
        CP      D
        JP      NZ,LOOPW2
        RET
;
;
```

```
;
;
;       *****************************************************
;       *THE WRICLK ROUTINE IS USED TO INITIALIZE THE REAL TIME*
;       *CLOCK UPON FIRST POWER ON OR WHEN NECESSARY.  THE RTC *
;       *REGISTERS ARE LOADED WITH THE ACTUAL TIME OF INITIAL- *
;       *ISATION; THIS INFORMATION IS SET ON THE SWITCHED ROM'S*
;       *ON POWER UP WITH THE RTC FLAG SET.                    *
;       *****************************************************
;
;
;
;
WRICLK: LD      A,10H           ;HOLD PULSE
        OUT     (9),A
        LD      A,20H           ;TIMER
MIN:    DEC     A
        JP      NZ,MIN
        LD      A,B             ;ADDRESS
        OUT     (11H),A
        LD      A,30H           ;WRITE TO RTC
        OUT     (9),A
        LD      A,0
        OUT     (9),A           ;ALL CONTROL SIGNALS LOW AGAIN
        RET
;
;
;
;       *****************************************************
;       *THE 31BIT BY 15BIT DIVIDE ROUTINE IS UNSIGNED AND     *
;       *DIVIDES THE DATA IN THE  HLB'C'  REGISTERS BY DATA IN *
;       *THE DE PAIR.  TEMPORARY OUTPUT IS IN H'L'D'.E' AND E' *
;       *IS TESTED TO SEE IF THERE SHOULD BE ROUNDING UP. FINAL*
;       *OUTPUT IS IN THE HL REGISTER PAIR.                    *
;       *****************************************************
;
;
;
;
DIV16:  EXX                     ;EXCHANGE REGISTER BANKS
        LD      HL,0            ;ZERO   RESULT REGISTERS
        LD      DE,0
        EXX
        LD      B,19H           ;CYCLE 25 TIMES
        LD      (DEN),DE        ;STORE DENOMINATOR
DIV:    LD      DE,(DEN)        ;LOAD DENOMINATOR INTO DE
        XOR     A               ;CLEAR CARRY
        LD      (NUM),HL        ;SAVE MSWORD OF NUMERATOR
        SBC     HL,DE           ;SUBTRACT
        JP      C,VOID          ;IF DEN>NUM THEN SHIFT ZERO INTO RESULT
        SCF                     ;ELSE SHIFT ONE IN
WUN:    EXX
        RL      E               ;SHIFT SHIFTED BIT ABOVE THROUGH ALL REGISTERS
        RL      D
        RL      L
        RL      H
        SLA     C               ;SHIFT ZERO INTO NUMERATOR
        RL      B
        EXX
        RL      L
        RL      H
        DJNZ    DIV
        JP      ROUND
VOID:   XOR     A               ;CLEAR CARRY
        LD      HL,(NUM)        ;GET NUMERATOR BACK
        JP      WUN
```

```
ROUND:  EXX
        LD      A,E             ;GET REMAINDER FROM E'
        CP      80H             ;COMPARE
        JP      M,LEAVE         ;IF MINUS THEN LEAVE AS IS
        INC     D               ;IF >= 0.5 THEN INCREMENT D'
LEAVE:  LD      A,L             ;PUT L' IN ACCUMULATOR
        EXX                     ;GET MAIN BANK
        LD      H,A             ;LOAD H WITH L'
        EXX                     ;GET ALTERNATE BANK
        LD      A,D             ;PUT D' IN ACCUMULATOR
        EXX                     ;GET MAIN BANK
        LD      L,A             ;LOAD L WITH D'
        RET
;
;
;
;
;
;       ********************************************************
;       *THE REFORM ROUTINE SWITCHES THE DE AND HL REGISTERS   *
;       *AND TAKES THE NEW LSWORD IN DE AND PUTS IT IN B'C'    *
;       ********************************************************
;
;
;
;
REFORM: EX      DE,HL           ;PUT DE IN HL PAIR
        LD      (TEMP1),DE      ;STORE LSWORD TEMPORARILY
        EXX
        LD      BC,(TEMP1)      ;LOAD DE INTO B'C'
        EXX
        RET
;
;
;
;
;       ********************************************************
;       *THE BLOCK ROUTINE TRANSFERS THE PRINT BLOCK FROM ROM  *
;       *TO RAM READY FOR THE NUMERICS TO BE LOADED INTO THE   *
;       *APPROPRIATE AREAS.                                    *
;       ********************************************************
;
;
;
BLOCK:  LD      DE,RAMBLK       ;LOAD DE WITH DESTINATION RAM POINTER
        LD      HL,PRBLK        ;LOAD HL WITH ORIGIN ROM POINTER
        LD      BC,RAMCNT       ;LOAD BC WITH NUMBER OF BYTES TO TRANSFER
        LDIR                    ;BLOCK TRANSFER
        RET
;
;
;
;
;
;       ********************************************************
;       *THE LORTC ROUTINE TAKES THE DATA ON THE SWITCHED ROM'S*
;       *AND WRITES THIS INFORMATION TO THE RTC WHEN THE RTC   *
;       *FLAG IS HIGH.  THE SWITCH DATA SHOULD BE SET UP TO    *
;       *CONTAIN THE ACTUAL TIME OF INITIALISATION.            *
;       ********************************************************
;
;
;
LORTC:  LD      A,(RTCFLG)      ;SEE IF RTC FLAG IS SET
        BIT     7,A
        RET     Z               ;IF NOT SET THEN NO NEED TO INITIALISE RTC
```

```
        LD      A,0CFH          ;SET UP PIO1 AND PIO3. PIO3 CHANNEL B TO
        OUT     (13H),A         ;HAVE ALL ITS PINS DESIGNATED AS OUTPUTS
        LD      A,0
        OUT     (13H),A
        LD      B,0             ;GET RTC ADDRESS
        CALL    WRICLK          ;CLEAR  SECONDS UNITS
        LD      B,1             ;TENS OF SECONDS ADDRESS
        CALL    WRICLK          ;CLEAR TENS OF SECONDS
        LD      C,2             ;NEXT RTC ADDRESS
        LD      HL,MONMIN       ;GET SWITCHED ROM ADDRESS
TM:     LD      A,(HL)          ;GET DATA FROM SWITCHED ROM - PUT IN ACC
        AND     0F0H            ;GET MSNIBBLE
        OR      C               ;ADD TO ADDRESS NIBBLE
        LD      B,A             ;TRANSFER TO B TO PASS TO WRICLK ROUTINE
        CALL    WRICLK          ;LOAD INTO RTC
        INC     H               ;NEXT SWITCH ADDRESS
        INC     C               ;NEXT RTC ADDRESS
        LD      A,9             ;ADDRESS COUNTER
        CP      C               ;FINISHED YET?
        JP      NZ,TM           ;NO, SO GO BACK
        LD      HL,RTCFLG       ;YES, SO LET'S START ON LSNIBBLE
TIM:    LD      A,(HL)          ;REPEAT ABOVE PROCEDURE FOR LSNIBBLES
        AND     0FH             ;MASK FOR LOWER 4 BITS
        SLA     A               ;LEFT JUSTIFY
        SLA     A
        SLA     A
        SLA     A
        OR      C               ;JOIN TO ADDRESS NIBBLE
        LD      B,A             ;TRANSFER TO B TO PASS TO WRICLK
        CALL    WRICLK
        INC     H               ;NEXT SWITCH ADDRESS
        INC     C               ;NEXT RTC ADDRESS
        LD      A,0DH           ;ADDRESS COUNTER
        CP      C
        JP      NZ,TIM          ;NOT FINISHED SO GO BACK
        LD      A,0CFH
        OUT     (13H),A
        LD      A,0F0H
        OUT     (13H),A
        RET
;
;
;
;
;       *******************************************************
;       *THE BCDCON ROUTINE USES THE BCD ROUTINE TO CONVERT THE*
;       *BINARY NUMBER IN THE HL PAIR TO A BCD NUMBER.THIS DATA*
;       *IS THEN LOADED INTO RAM AS WELL AS BEING DISPLAYED ON *
;       *LED'S.                                                *
;       *******************************************************
;
;
;
;
BCDCON: CALL    BCD             ;CONVERT THE BINARY NUMBER TO BCD
        PUSH    IY              ;TRANSFER IY CONTENTS TO HL
        POP     HL
        EXX
        LD      A,C             ;GET DIGIT THREE FROM C'
        EXX
        AND     0FH             ;MASK FOR LOWER 4 BITS
        LD      (HL),A          ;MSDIGIT INTO LED
        LD      (IX),A          ;LOAD RAMBLOCK WITH MSDIGIT
        EXX
        LD      A,D             ;GET NEXT SIGNIFICANT DIGIT FROM D'
        EXX
```

```
        SRL     A               ;RIGHT JUSTIFY
        SRL     A
        SRL     A
        SRL     A
        DEC     H               ;NEXT LED ADDRESS
        LD      (HL),A          ;LOAD LED
        LD      (IX+1),A        ;LOAD RAMBLOCK
        EXX
        LD      A,D             ;GET LSNIBBLE FROM D'
        EXX
        AND     0FH             ;MASK FOR LOWER 4 BITS
        DEC     H               ;NEXT LED ADDRESS
        LD      (HL),A          ;LOAD LED WITH LSDIGIT
        LD      (IX+2),A        ;LOAD RAMBLOCK
        RET
;
;
;
;
;       ********************************************************
;       *THE BCD ROUTINE CONVERTS A BINARY NUMBER TO BCD FORMAT*
;       *  -  NUMBER IS PASSED IN HL REGISTER PAIR.  RESULT AS *
;       *FOLLOWS:   DIGIT 5 - LOWER 4 BITS OF REG B'           *
;       *                 4 - HIGH  4 BITS OF REG C'           *
;       *                 3 - LOWER 4 BITS OF REG C'           *
;       *                 2 - HIGH  4 BITS OF REG D'           *
;       *                 1 - LOWER 4 BITS OF REG D'           *
;       *ONLY THE DIGITS 3,2,1 ARE USED.                       *
;       ********************************************************
;
;
;
;
BCD:    LD      DE,2710H        ;LOAD DE WITH 10,000 DECIMAL
TENS:   CALL    UNIT            ;SUBTRACT POWERS OF 10 FROM NUMBER
        EXX
        LD      B,A             ;RESULT IN ALTERNATE B'
        EXX
        LD      DE,3E8H         ;1000 DECIMAL
THOUS:  CALL    UNIT
        CALL    MODIFY          ;ROTATE LOWER BYTE TO UPPER POSITION
        EXX                     ;SAVE IN OTHER BANK
        LD      C,A             ;DIGIT 4 IN UPPER NIBBLE OF C'
        EXX
        LD      DE,64H          ;100 DECIMAL
HUND:   CALL    UNIT
        EXX
        OR      C               ;3 AND 4 DIGITS COMBINED
        LD      C,A
        EXX
        LD      DE,0AH          ;10 DECIMAL
TEN1:   CALL    UNIT
        CALL    MODIFY
        OR      L               ;1 AND 2 DIGITS COMBINED
        EXX
        LD      D,A             ;RESULT IN D'
        EXX
        RET
;
;
;
;
;       ********************************************************
;       *THE UNIT ROUTINE SUBTRACTS POWERS OF 10 FROM THE NUM- *
;       *BER IN THE HL PAIR.                                   *
;       ********************************************************
```

```
;
;
;
;
UNIT:   LD      A,0FFH          ;COUNTER = -1
ABOVE:  INC     A               ;INCREMENT COUNTER
        OR      A               ;CARRY CLEARED
        SBC     HL,DE           ;SUBTRACT POWERS OF 10
        JR      NC,ABOVE        ;CONTINUE SUBTRACTING UNTIL RESULT IS NEGATIVE
        ADD     HL,DE           ;RESTORE NUMBER IF OPERATION WAS NEGATIVE
        RET
;
;
;
;
;
;       ********************************************************
;       *THE MOD ROUTINE ROTATES THE NUMBER IN THE ACCUMULATOR *
;       *FOUR PLACES TO THE LEFT.                              *
;       ********************************************************
;
;
;
MODIFY: AND     0FH             ;CLEAR UPPER BITS
        RLCA
        RLCA
        RLCA
        RLCA
        RET
;
;
;
;
;
;       ********************************************************
;       *THE MULSUB ROUTINE ACCOMPLISHES A MULTIPLE SUBTRACT.  *
;       *THE HL REGISTER POINTS TO THE DESTINATION MSBYTE AND  *
;       *THE DE TO THE SOURCE MSBYTE.  THE DESTINATION OPERAND *
;       *IS SUBTRACTED FROM THE SOURCE AND THE RESULT PLACED   *
;       *BACK IN THE DESTINATION LOCATION.  THE C REGISTER HAS *
;       *THE WIDTH IN BYTES OF THE SOURCE AND DESTINATION OPER-*
;       *ANDS.  THE CARRY IS SET TO REFLECT THE LAST (MS) CARRY*
;       ********************************************************
;
;
;
;
;
MULSUB: LD      B,0             ;CLEAR B - C CONTAINS NUMBER OF BYTES
        ADD     HL,BC           ;POINT TO DESTINATION LSBYTE+1
        DEC     HL              ;POINT TO LSBYTE
        EX      DE,HL
        ADD     HL,BC           ;POINT TO SOURCE LSBYTE+1
        DEC     HL              ;LSBYTE
        EX      DE,HL
        OR      A               ;CLEAR BORROW
GOMORE: LD      A,(DE)          ;GET SOURCE BYTE
        SBC     A,(HL)          ;SOURCE MINUS DESTINATION MINUS CARRY
        LD      (HL),A          ;STORE RESULT
        DEC     HL              ;DESTINATION POINTER DECREMENTED
        DEC     DE              ;SOURCE POINTER DECREMENTED
        DEC     C               ;BYTE COUNT DECREMENTED
        JR      NZ,GOMORE       ;GO IF NOT ALL SUBTRACTS DONE
        RET
;
;
```

```
;
;
;          ****************
;          *DELAY ROUTINES*
;          ****************
;
;
;
COUNT:     LD       DE,25H
LOOPW:     DEC      DE
           LD       A,0FFH
CIRC:      DEC      A
           JP       NZ,CIRC
           XOR      A
           CP       D
           JP       NZ,LOOPW
           CP       E
           JP       NZ,LOOPW
           RET
;
;
;
;
BIGCNT:    LD       DE,500H
LOOPW1:    DEC      DE
           LD       A,0FFH
CIRC1:     DEC      A
           JP       NZ,CIRC1
           XOR      A
           CP       D
           JP       NZ,LOOPW1
           CP       E
           JP       NZ,LOOPW1
           RET
;
;
;
;
CNT17:     LD       DE,2CD0H
LOOPW3:    DEC      DE
           LD       A,0FFH
CIRC3:     DEC      A
           JP       NZ,CIRC3
           XOR      A
           CP       D
           JP       NZ,LOOPW3
           CP       E
           JP       NZ,LOOPW3
           RET
;
;
;
;
;
FIVMIN:    LD       E,3
LPX4:      DEC      E
           LD       HL,0FFFFH
LPX5:      DEC      HL
           LD       B,0FFH
LPX6:      DEC      B
           JP       NZ,LPX6
           XOR      A
           CP       H
           JP       NZ,LPX5
           CP       L
           JP       NZ,LPX5
```

```
        CP      E
        JP      NZ,LPX4
        RET
;
;
;
;
;       ********************************************************
;       *THE  ZERPRI  ROUTINE  MAKES  THE  DECISION  TO  DO  A *
;       *BLEED/ZERO  AND  PRINT OUT  THE  PRINT BLOCK BASED ON *
;       *PRIFLG BEING SET. THE OPERATION WILL OCCUR BY EXTERNAL*
;       *MANUAL OPERATION AS INITIATED BY THE 1/DAY-CONTINUOUS *
;       *SWITCH OR  ONCE EVERY DAY  AS SET ON THE  TIME SWITCH *
;       *FOUND IN THE SWITCHED ROM AREA.                       *
;       ********************************************************
;
;
;
;
ZERPRI: IN      A,(9)           ;GET PRINT FLAG INFORMATION FROM PIO
        BIT     1,A             ;LOOK AT APPROPRIATE BIT
        JP      NZ,PRINT1       ;IF IT'S SET THEN ZERO/PRINT THREE TIMES
        LD      B,4             ;GET HOURS - UNITS OFF RTC
        CALL    REDCLK          ;READ THE RTC
        LD      D,A             ;SAVE HOURS - UNITS IN D REGISTER
        LD      B,5             ;GET HOURS - TENS OFF RTC
        CALL    REDCLK          ;READ THE RTC
        AND     3               ;MASK FOR TWO LOWER BITS
        LD      B,0AH           ;MULTIPLICAND IN B
        CALL    MUL8            ;HL CONTAINS TENS OF HOURS TIMES 10 DECIMAL
        LD      A,L             ;STORE IN ACCUMULATOR
        ADD     A,D             ;ADD UNITS TO TENS
        LD      C,A             ;STORE IN C
        LD      A,(PRITIM)      ;GET PRINT TIME OFF SWITCHED ROMS
        SRL     A               ;RIGHT JUSTIFY
        SRL     A
        SRL     A
        CP      C               ;ARE WE AT ZERO/PRINT HOUR?
        JP      NZ,LAST1        ;IF NOT,  THEN BRANCH
        LD      A,(PRIFLG)      ;LOOK AT ZERO/PRINT FLAG TO SEE IF SET
        OR      A               ;SET/RESET ZERO IN ZERO/PRINT FLAG
        RET     NZ              ;IF SET THEN DON'T ZERO/PRINT AGAIN
        LD      A,0FFH          ;SET ACCUMULATOR TO ALL ONES
        LD      (PRIFLG),A      ;ZERO/PRINT FLAG NOT SET PREVIOUSLY, SO SET NOW
PRINT1: CALL    SUBPRO          ;ZERO AND PRINT THREE TIMES
        CALL    SUBPRO
        CALL    SUBPRO
        RET                     ;DONE THREE TIMES,  LET'S LEAVE
LAST1:  LD      A,0             ;ZERO ACCUMULATOR
        LD      (PRIFLG),A      ;RESET PRINT FLAG
        RET
;
;
;
;
;       ********************************************************
;       *THE SUBPROG ROUTINE CALLS THE BULK OF THE MAIN PROGRAM*
;       *AND IS USED IN THE ZERO/PRINT ROUTINE 'ZERPRI' TO RUN *
;       *THE SYSTEM THROUGH A BLEED,  ZERO, AND  DATA SEQUENCE *
;       *THREE TIMES, THE RESULTS BEING PRINTED OUT EACH TIME. *
;       ********************************************************
;
;
;
SUBPRO: CALL    RETN
        CALL    TESTK
```

```
        CALL    PRESS
        CALL    VELOC
        CALL    LIFT
        CALL    FLOW
        CALL    DISP
        CALL    SITE
        RET
;
;
;
;
;
;       ********************************************************
;       *THE RETN ROUTINE SIMPLY DISCOVERS WHETHER A RETURN TO *
;       *THE POWER IN TESTK ROUTINE WILL ENABLE THE TIMER TO BE*
;       *STARTED WITH THE RISING EDGE OF THE KWH INPUT SIGNAL  *
;       *AND THUS MEASURE THE FULL CORRECT TIME.               *
;       ********************************************************
;
;
;
;
RETN:   IN      A,(9)           ;LOOK AT THE KWH SWITCH
        BIT     0,A             ;INFORMATION IN BIT ZERO
        JP      NZ,RETN         ;IF STILL HIGH THEN WAIT UNTIL LOW
        RET
;
;
;
;
;

;
;       ********
;       *TABLES*
;       ********
;
;
;
WKDAY:  DB      'SUMOTUWETHFRSA'
MONTH:  DB      '   JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC'
PRBLK:  DB      'SITE#X XX XX XXX XX'
        DB      'TIME XX:XX:XX      '
        DB      'EFFICIENCY(%) XX.X '
        DB      'POWER IN (KW) XX.X '
        DB      'LIFT (FEET)  XXX   '
        DB      'FLOW (CFS)     X.XX'
;
;
;
.DEPHASE
END
```